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REVIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT

ELECTRONICS • NAVIGATION • GUIDANCE • CONTROL

May / 1958

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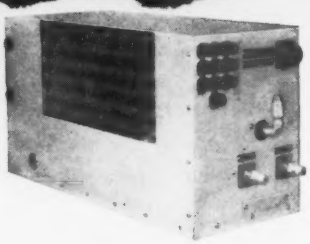

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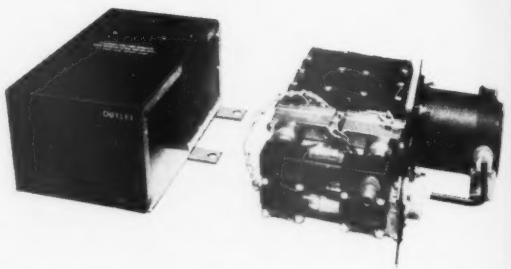

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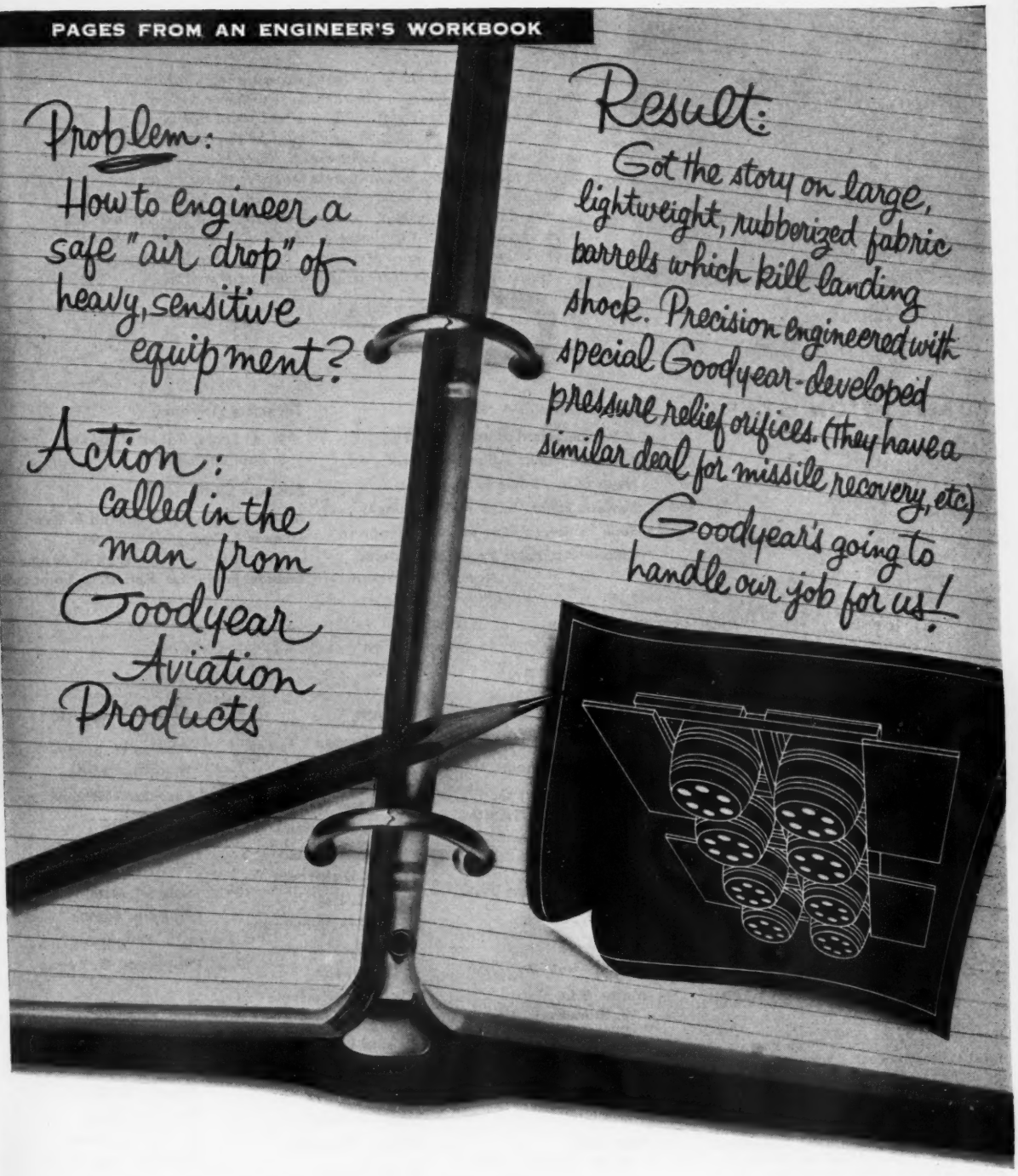

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On our cover

An illustration from one of the many exclusive technical articles in this special issue depicts a nuclear interplanetary vehicle and its guidance companion (right). The manned spacecraft, consisting of a large cross-shaped gondola (shape dictated by directional thrust control requirements) towed by a nuclear-heated power plant, can be set in rotation to provide centrifugal weight for the crew during months-long coasting. The guidance companion, also nuclear powered, takes position fixes and transmits optical observations and navigational data to the manned craft. The drawing, from Krafft A. Ehricke's paper "Our Philosophy of Space Missions" (p. 38), is by John Sentovic, of Convair, A Division of General Dynamics Corporation.

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. . . formerly *Aeronautical Engineering Review*, is published monthly by the Institute of the Aeronautical Sciences, Inc., at 20th and Northampton Streets, Easton, Pa. Headquarters and Editorial Offices: 2 East 64th Street, New York 21, N.Y. (TEmpleton 8-3800). Western Office: 7660 Beverly Blvd., Los Angeles 36, Calif.

Subscription rates: United States and possessions, 1 year, $5.00; single copies, $0.50. Foreign countries including Canada (American currency rates), 1 year, $6.00; single copies, $0.50.

Second-class mail privileges authorized at Easton, Pa. Acceptance for mailing at a special rate of postage as provided for in the Act of August 24, 1912.

Notices of change of address should be sent to the Institute of the Aeronautical Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to actual change of address.

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formerly
AERONAUTICAL ENGINEERING REVIEW

AERO/SPACE ENGINEERING

VOLUME 17 / NUMBER 5 May 1958

Featured in this issue

L. V. Berkner **28** The Challenge Is Here—NOW (Guest Editorial)

William H. Dorrance **30** Hypersonic Aerodynamic Factors In Performance, Guidance, and Control

Edward G. Schwarm **34** Electronic Simulation for the Jet Age

Krafft A. Ehricke **38** Our Philosophy of Space Missions

Mortimer Rogoff **44** Radio Navaids for Long-Range Flight

J. C. Fletcher **50** Guidance and Control Problems in the Air Force Ballistic Missile Program, Part I

Barry J. Baron and Rodney W. Unold **55** Multipurpose Automatic Navigator

Robert E. Wilson and John B. Lewis **60** Cross Coupling in Inertial Navigation Systems

R. W. Powell and W. M. Kauffman **66** Infrared Application to Guidance and Control

Gordon E. Click and Robert G. Halliday **72** Rocket Test Stand Pressure Controller Design

James P. Monroe **78** Random Vibration Testing for Evaluation of Electronic Components for Aircraft and Missile Environments

J. R. Iverson **81** Advanced Doppler Navigation for the U.S. Army

Departments

17 IAS News Notes
21 IAS News
27 Dateline World
87 Reviews
99 International Abstracts
147 IAS Corporate Members
155 Books
161 Personnel Opportunities
162 Index to Advertisers
163 New Products and Literature

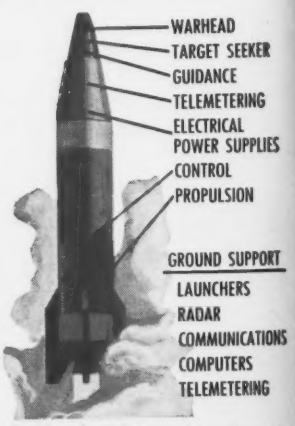
Photo shows test of a missile guidance system under simulated flight conditions at Bendix Research Laboratories Division.

BENDIX "FLIES" MISSILES IN THE LAB— SAVES YEARS OF TIME AND MILLIONS OF DOLLARS

Missiles cost big money—there's no avoiding that fact. But Bendix research has helped shorten development and production time and has saved millions by designing several specialized devices called Missile Flight Simulators for advanced scientific testing.

It not only takes a lot of time to test a missile by actual firing, but it is wasteful to fire without having previously evaluated every phase of engineering design to minimize failure of these unbelievably complex space vehicles. Thus in determining guidance system performance, for example, as many as 200 "ground flights" can be made in a day on Bendix Missile Simulators. Every reaction of the system is recorded on tape so that experts can study instant-by-instant performance under varying conditions. Missile speed, space orientation, wind characteristics, range and speed of the target are simulated and related mathematically within analog and digital computers to provide realistic flight conditions.

Research and development are among the many important activities of Bendix in the missile field. In addition, Bendix has engineered, developed and manufactured many of the major systems used in key missiles as indicated in the illustration at the right. Bendix also builds the surface-to-air Talos missile for the U. S. Navy. It will be the major armament of the U. S. cruiser "*Galveston*" and will also be installed on a number of other cruisers including the nuclear powered "*Long Beach*".



Bendix furnishes major elements for missiles of all types. This illustration represents no particular missile, but shows the general location of various airborne Bendix systems and their components. In addition, Bendix produces the Ground Support systems indicated above.

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IAS News Notes

May 1958

We hope you like your magazine's new name.
Many months of planning went into the change.
For details see page 21.

SOME 100 HIGH LEVEL officials - IAS Corporate Member Representatives and the Aircraft Industries Association Missiles Committee - attended a two-day Secret conference at Patrick AFB and Cape Canaveral last month, at the invitation of Major General Donald N. Yates, Commander, Air Force Missile Test Center. Details about the field trip will be carried in the June issue.

PRINCIPAL SPEAKER at the IAS National Summer Meeting, July 8-11, will be H. Guyford Stever, Chairman, NACA Special Committee on Space Technology. Dr. Stever will speak on "A Space Technology Program for America" at a banquet-dance on July 10. The technical program will stress balanced sessions on aircraft, missiles and space subjects. Technical sessions will be held at the Ambassador Hotel, Los Angeles.

NATIONAL MEETINGS CALENDAR

May 12-14	National Midwestern Meeting on Guided Missiles (CLASSIFIED), Hotel Chase, St. Louis, Mo.
May 12-14	National Conference on Aeronautical Electronics, Dayton, Ohio. IRE-IAS participating.
June 2-4	National Telemetering Conference, Lord Baltimore Hotel, Baltimore, Md. Sponsored by IAS, ARS, ISA, and AIEE.
June 19-20	1958 Heat Transfer and Fluid Mechanics Institute, University of California, Berkeley. Cosponsored by IAS.
July 8-11	National Summer Meeting, Ambassador Hotel, Los Angeles, Calif.
Sept. 8-13	First International Congress, International Council of the Aeronautical Sciences. Headquarters at the Palace Hotel, Madrid, Spain.
Oct. 7-8	Canadian Aeronautical Institute-IAS 1958 Joint Meeting, Chateau Laurier, Ottawa, Canada.
Dec. 17	Wright Brothers Lecture, Washington, D. C.
1959	
Jan. 26-29	Twenty-Seventh Annual Meeting, Sheraton-Astor Hotel, New York. Honors Night Dinner, Tuesday, January 27.

THE INSTITUTE MOURNS the loss of three of its members: Major James H. Doolittle, Jr., (A), 38, who died April 9; Raymond T. Lewis (M), who died March 31; and Lt. Robert K. Hughson (A), killed in a T-33 crash at Laredo AFB on February 24. Major Doolittle was the son of James H. Doolittle (HF), IAS 1940 President. Mr. Lewis had been Manager, Commercial Engine Sales, General Electric Company, Aircraft Gas Turbine Division.

REGIONAL STUDENT CONFERENCES

May 1-3 Middle-Atlantic: Pennsylvania State University, University Park, Pennsylvania.

May 6 Detroit: University of Michigan, Ann Arbor, Michigan. Sponsored by Detroit Section.

May 7-9 West Coast: Los Angeles, California. Sponsored by Los Angeles Section.

SECTION MEETINGS CALENDAR

May 10 San Diego Section: Spring Dance, IAS Building, 8 p.m.

May 13 Los Angeles Section: Specialist Meeting, IAS Building, 8 p.m. "Space Flight Mechanics" by R. W. Buckheim.

May 13 Washington Section: Dinner Meeting, Occidental Restaurant. (Social at 6, dinner at 6:45). "History of Aviation" by Paul E. Garber.

May 14 Texas Section: Specialist Meeting (CLASSIFIED), Arlington State College, 8 p.m. "High Speed Escape Systems Stability" by Ernest Kistler.

May 15 Los Angeles Section: Dinner Meeting, IAS Building. (Social at 6, dinner at 7). "Airlift - A Discussion of Air Logistic Transportation" by L. T. Peyton.

May 16 San Antonio Section: Dinner Meeting (commemoration of Armed Forces Day), Kelly AFB Officers Club. (Social at 6:30, dinner at 7:30). "The History, Importance and Future of ICBMs" by K. J. Bossart.

May 17 Rocky Mountain Section: Dinner Dance, Glenn Miller Ballroom, University of Colorado, 7 p.m.

May 20 San Diego Section: Panel Discussion, IAS Building, 8 p.m. "High Speed Wind Tunnels", W. T. MacCarthy, Moderator.

May 23 Texas Section: Dinner Meeting, Western Hills Inn. (Social at 7, dinner at 8). "The Development of Our Space Capability" by Krafft Ehricke.

May 25 New York Section: Afternoon Picnic Meeting, Dynamic Development Corporation, Babylon, L.I. Staff engineers of this firm will describe principles of hydrofoil boats and present a demonstration.

May 27 Los Angeles Section: Specialist Meeting, IAS Building, 8 p.m. "Experimental Investigation of Supersonic Laminar Boundary Layer Stability in Transition" by John Laufer.

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IAS News

. . . a record of people and events of interest to Institute Members

New Packaging for the *Aeronautical Engineering Review*

No need to belabor the point here that the interests of the Institute, in general, and those of the *Aeronautical Engineering Review*, in particular, have long since been extended far beyond the boundaries originally conceived by their founders. Evolutionary processes have been at work and have lately gained new impetus. In a very short period of time, one of man's greatest dreams, space exploration, has become reality.

Many years before Sputnik I appeared over the horizon, Institute members in Institute meetings were discussing the possibilities of flight outside the limits of the earth's atmosphere. As was pointed out editorially in the December, 1957, *Review*, the Institute's concern with the basic considerations for hypersonic, extraterrestrial flight is long-standing, and the data on which design for current missiles and space vehicles were predicated were, in many cases, presented first in IAS meetings and in IAS publications.

Looking back over past volumes of the *Aeronautical Engineering Review*, it has been increasingly evident that the subject matter covered has trended away from the areas originally implicit in the magazine's title. With the accelerating tempo of space exploration as recognized by the President in his recent message to Congress, there was little doubt that an increasing percentage of content of the *Review* would be devoted to problems of space technology.

With these facts in mind, an intensive search was made for new and more appropriate labels for your magazine. Some months ago staff studies were presented to the Executive Committee of the Council, and it was agreed that the time had come to change the name of the *Review* to bring it more nearly into line with its actual content. After a long process of trial, error, and experimentation, the title that appears for the first time on this issue was chosen. It will be recognized that the new wording not only points up the extension of our interests into the areas beyond the earth's atmosphere, but also recognizes that basic aeronautical engineering is still, and will continue to be, a very important part of our coverage. A large part of our industry will be vitally concerned with air-breathers with wings for many years to come and must not be neglected for the more glamorous requirements of space travelers. Also the subtitle is consistent with the original concept of the magazine, a Review of the important new technological trends in all fields of interest to Institute members.

Finally, no radical changes in editorial policies are contemplated under the new title. We will, with the help of our editorial committees, do our best to sense the trends of interest of our members. We will then strive to meet their requirements for information essential to them in their professional lives. As we have said before, through these pages the Institute will continue to serve the best interests of its membership "at all altitudes from Zero to Infinity."

S. Paul Johnston

DIRECTOR

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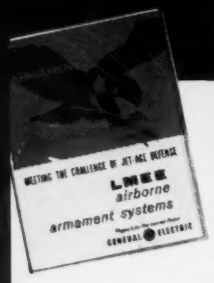
ARMAMENT

LMEE arms the Lockheed F-104-Starfighter



LMEE fire control systems put lethal talons in the F-104's offensive power . . . can assist the pilot of such supersonic aircraft to detect, pinpoint, track and destroy an attacking aircraft. LMEE fire control systems can be integrated with navigation and flight control systems, electronic countermeasures and pilot displays. ➢ ➢ Fire control systems are only one of many LMEE airborne systems which help to power the peace. ➢ ➢ For brochure . . . "Meeting the Challenge of Jet Age Defense" . . . **Write Dept. 1E.**

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Equipment Displays, 16 Sessions Set for Telemetering Conference

Nine Nations, Including Russia, to Participate

A PROGRAM of 16 technical sessions has been announced for the 1958 National Telemetering Conference, June 2–4, at the Lord Baltimore Hotel, Baltimore, Md. The conference is sponsored by the IAS, ARS, ISA, and AIEE.

Nations contributing technical papers include: the United States, France, Canada, Sweden, Switzerland, Australia, Italy, Great Britain, and Russia—the latter participating in the IGY II session.

Principal speaker at a banquet on June 3 will be Adm. Blinn Van Mater, USN (Ret.); he will discuss "Telemetering in the IGY."

General Earle Cook, Director, U.S. Army Signal Engineering Laboratories, will discuss "Telemetering Requirements of the U.S. Army" at a luncheon on June 2.

Sessions

The following sessions have been scheduled:

Monday, June 2—*morning:* Industrial Telemetering I, W. E. Rufleth, The Bristol Company, Chairman; Pickups, W. Wildhack, National Bureau of Standards, Chairman; Mobile Airborne I, G. P. Stout, Aeronca Manufacturing Corporation, Chairman.

Afternoon: Industrial Telemetering II, W. E. Phillips, Leeds & Northrup Co., Chairman; Medical, Lt. Comdr. B. Halstead, USN (MC), Bethesda Naval Hospital, Chairman; Mobile Airborne II, J. P. Randolph, Applied Physics Laboratory, Johns Hopkins University, Chairman.

Tuesday, June 3—*morning:* IGY I, H. Odishaw, National Academy of Sciences, Chairman; Data Processing I, Ken Uglow, Ken Uglow, Inc., Chairman.

Afternoon: IGY II, Admiral Gordon Caswell, USN (Ret.), Chairman; Data Processing II, A. Gruer, Sandia Corporation, Chairman.

Wednesday, June 4—*morning:* Transistors, F. Coker, United Electrodynamics, Chairman; Mobile Systems I, K. E. V. Willis, British Joint Services Mission, Chairman; Mobile Ground, W. J. Mayo-Wells, Consultant, Chairman.

Afternoon: System Problems, panel discussion, L. Gardenhire, Radiation, Inc., Chairman; Mobile Systems II, L. Clark, Tele-Dynamics, Inc., Chairman.

A classified session (no title available) has been scheduled for Thursday morning. R. Colander, Bendix Pacific Division, is Chairman.

Field Trips

A visit to the Applied Physics Laboratory, Johns Hopkins University, has been scheduled for the afternoon of June 3. The Terrier and Talos missiles and the telemetering ground station used for checking and experimental work will be seen. This trip is limited to 75 persons.

Another trip on the evening of June 4 will be to The Martin Company's extensive flight test telemeter receiving and data processing facility. This is limited to 150.

An all-day visit is scheduled on June 4 to the Aberdeen Proving Ground's Ballistic Research Laboratory (see photo caption). This is limited to 120.

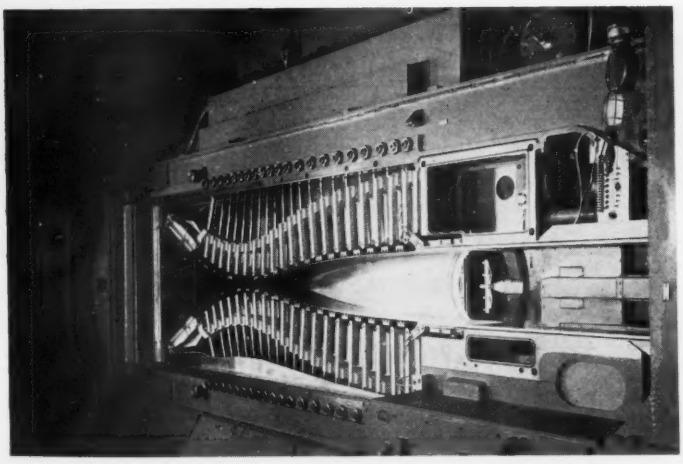
The banquet on Tuesday evening will be limited to 550.

Leading telemetering manufacturers will show and demonstrate their latest equipment. Many exhibits will tie in with technical papers, providing an opportunity both to see the equipment and to hear how it is used.

Registration facilities will be open on Sunday, June 1.

✦ ✦ ✦

Conference planners have scheduled a field trip on June 4 to the Aberdeen Proving Ground's Ballistic Research Laboratory where the Mach 5, flexible nozzle, 13- by 15-in. wind tunnel, IGY rockets, and ordnance museum will be visited. The tunnel is shown with its side wall removed. Flexible plates are positioned by means of jacks operated hydraulically. A calibration device is shown installed in the test section.



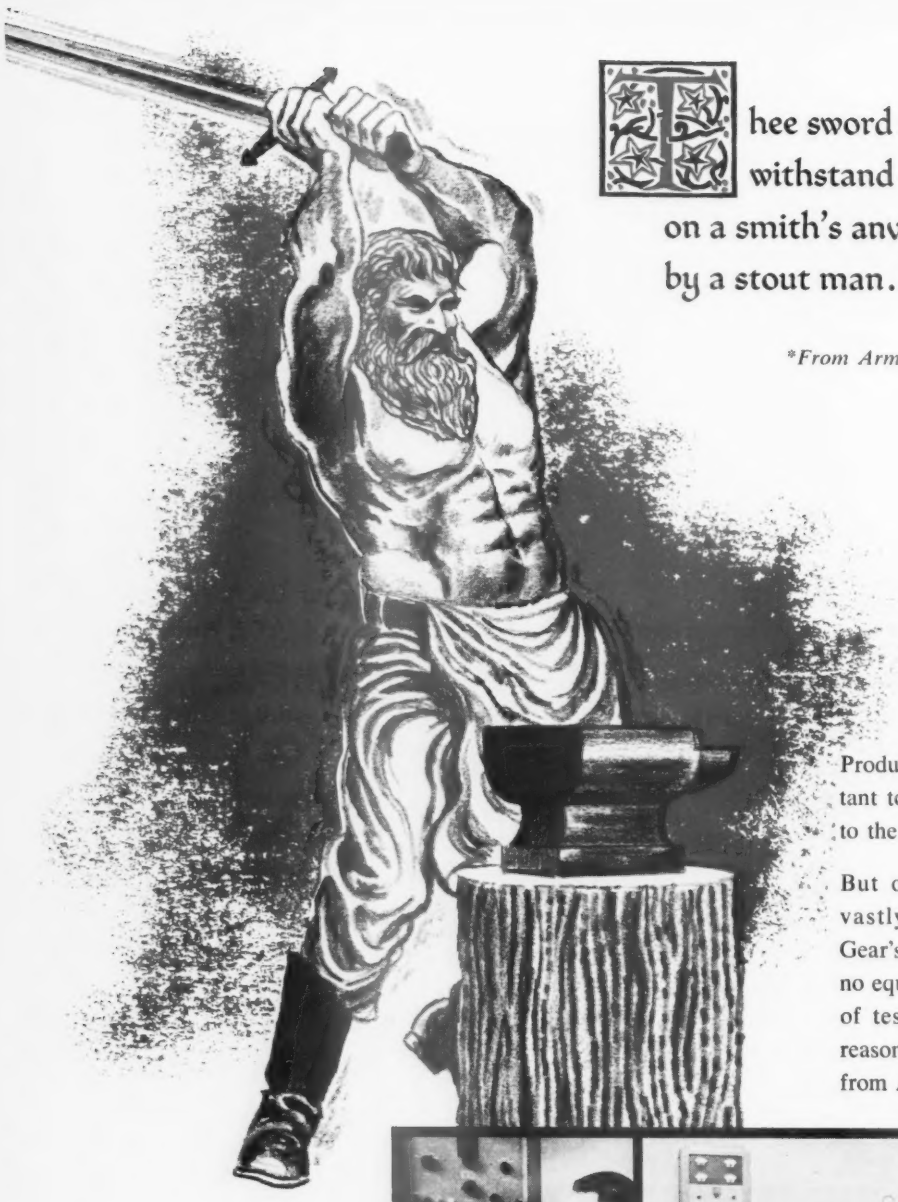
Four I.A.S. Members on NACA Subcommittees

Four IAS members at California Institute of Technology have been named to subcommittees of the National Advisory Committee for Aeronautics for 1958.

The members and their appointments are Lester Lees (AF), Professor, Aeronautical Engineering, Guggenheim Aeronautical Laboratory—fluid mechanics; Hans W. Liepmann (F), Professor, Aeronautical Engineering, C.I.T.—fluid mechanics; Clark B. Millikan (HF), Director, Guggenheim Lab. and Southern California Cooperative Wind Tunnel—high-speed aerodynamics (Chairman); and E. E. Sechler, Professor, Aeronautical Engineering, C.I.T.—aircraft.

Professor Ackeret Honored

A March 17 ceremony in Zurich, Switzerland, honored Prof. Jacob Ackeret (HF), on his sixtieth birthday. Dr. Ackeret, head of the Institute of Aerodynamics at the Federal Technical Institute of Zurich, was given the plates of the Title Page and List of Contents of a special issue of *The Journal of Applied Mathematics and Physics* (*ZAMP*). The issue, Volume 9-b, contains about 700 pages and consists of original papers written especially for the commemorative issue by Dr. Ackeret's former students.

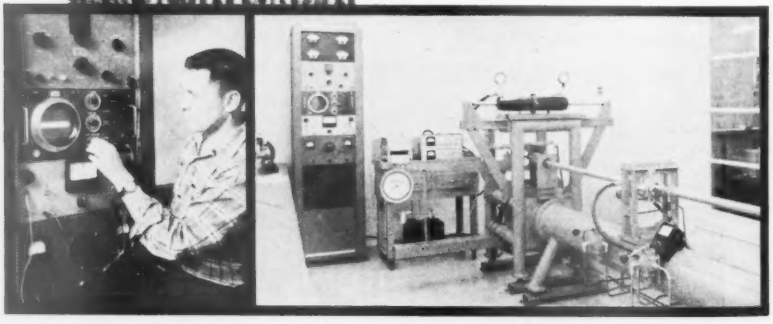


Thee sword must withstand a solid blow on a smith's anville by a stout man...*

*From Armourer's specifications, 1450.

Product testing is just as important to Advance Gear as it was to the swordsmith of old...

But our testing methods are vastly changed . . . Advance Gear's new testing laboratory has no equal in equipment or scope of testing technique, another reason you can expect perfection from Advance Gear.



A section of Advance Gear's testing laboratory. Gear systems for the Bomarc missile are tested here before delivery to Boeing.

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IAS News — News of Members

Harold E. Francis (M), former Assistant Chief Engineer, Wright Aeronautical Division of Curtiss-Wright Corporation, has been named Senior Staff Engineer, Chandler-Evans Division of Pratt & Whitney Co.

John Grosvenor (M) has joined the Guided Missile Research Division, The Ramo-Wooldridge Corporation, and will work mainly on test direction at the rocket test site, Edwards AFB, Calif. He formerly was Assistant Project Engineer, Flight Test Engineering, Wright Aeronautical Division, Curtiss-Wright Corporation.

Alan R. Gruber (M), formerly Manager, Engineering Department and a Director, Nuclear Development Corporation of America, has joined Marquardt Aircraft Company Astro Division as Assistant Chief Engineer in charge of nuclear systems research.

Paul E. Hovgard (F), formerly Vice-President, Kellett Aircraft Corporation, has been named Assistant to the President, Helio Aircraft Corporation. Mr. Hovgard will make his headquarters in Pittsburg, Kan., where the Helio Courier is manufactured.

Hilliard W. Paige (M), formerly Manager, Nose Cone Systems and Projects, Missile and Ordnance Systems Department, has been appointed Manager, Nose Cone Section.

E. Allan Williford (M) has announced that he will retire as President of Link Aviation, Inc. He will continue as a member of the firm's Board of Directors.

William W. Willmarth (A), Senior Research Fellow, California Institute of Technology and Consultant to The RAND Corporation, has been appointed Associate Professor of Aeronautical Engineering, University of Michigan, for the period March 1, 1958, to the end of the 1960–1961 academic year.

Edwin A. Link (AF), Chairman of the Board, Link Aviation, Inc., has been elected President of General Precision Equipment Corporation. He resigned as Vice-Chairman of General Precision's Board to assume his new position. Link Aviation is a subsidiary of General Precision.

IAS News — Corporate Member News

• **Aerojet-General Corporation** has announced a new research rocket, the Aerobee 100, which was flight tested by the Navy recently. Aerojet says it was developed with company funds to fill the need for a medium-performance, easy-to-operate, inexpensive rocket (50 to 100 miles altitude) for upper atmosphere research.

• **Aeronca Manufacturing Corporation** has developed a series of digital data handling devices said to be so modularized that combined functions can be performed by assembly of a series of modules: arabic to digital conversion, conversion of any binary code to any other binary code, digital comparison of voltage tolerance, and digital to arabic conversion.

• **Aeroquip Corporation** has announced the appointment of Lawrence L. Jacobs as Plant Manager of its Elbeeco Division. . . . Laurance S. Haynes, Jr., has been named Eastern Manager, General Logistics Sales.

• **Allis-Chalmers Manufacturing Company** has announced the appointment of E. F. Greiwe as Manager, Norwood Works Centrifugal Pump Department.

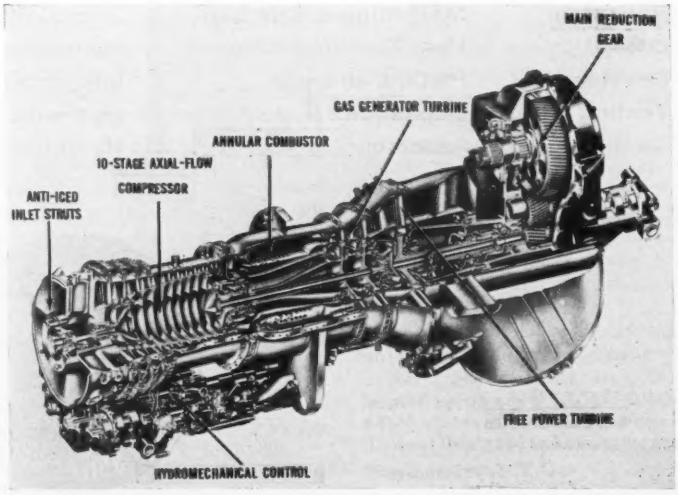
• **Allison Division, General Motors Corporation,** has formed a ten-man scientific Advisory Committee headed by Theodore von Kármán, Chairman of AGARD. Other members of the committee include Lawrence R. Hafstad, Vice-President in charge of the GM Research Staff; Luigi Crocco, Director, Guggenheim Jet Propulsion Center, Princeton University; John R. Markham, Professor, Aeronautical Engineering, M.I.T.; Courtland Perkins, Chairman, Aeronautical Engineering Department, Princeton; William R. Sears, Director, Graduate School of Aeronautical Engineering, Cornell University; Maurice J. Zucrow, Professor, Gas Turbines and Jet Propulsion, Purdue University; Pol Duwez and W. Duncan Rennie, Professors of Mechanical Engineering, C.I.T.; and Antonio Ferri, Professor, Aerodynamics, and Head, Aerodynamics Laboratory, Polytechnic Institute of Brooklyn.

• **American Airlines, Inc.,** has announced the election of three Executive Vice-Presidents: Charles A. Rheinstrom—Sales; O. M. Mosier—Operations; and William J. Hogan—Finance and Planning.

• **Bell Aircraft Corporation** has announced that all Buffalo and Niagara Frontier defense products activities will be operated by a newly established autonomous unit to be called Bell's Niagara Frontier Division. Ray P. Whitman, first Vice-President, will be General Manager.

(*Continued on page 150*)

General Electric Company's T-58 aircraft gas turbine in the cutaway view recently passed its 150-hour model test. The engine is said to have produced 1,065 military h.p. and to have bettered the military performance guarantee of 0.66 s.f.c. The engine weighs 325 lbs. and measures 59 in. in length and 16 in. in diameter.



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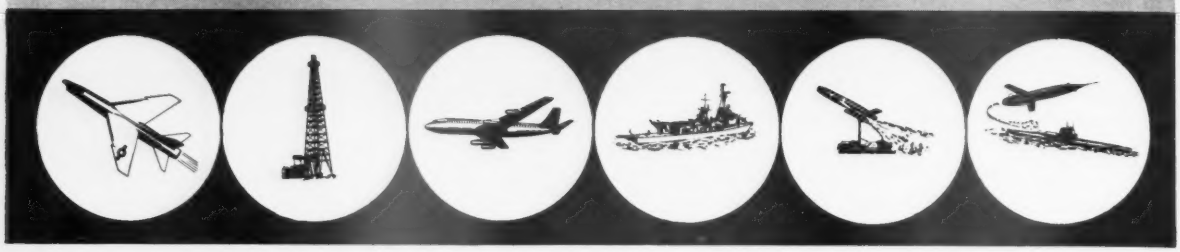

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DATELINE World

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

Detailed Data Disclosed on U.S.S.R.'s Il-18 Transport

◆ A Russian publication has recently contained detailed information on the Il-18, one of the new Soviet four-engine, turboprop transports. The Il-18, named the "Moskva" by the Soviets, is a product of the Ilyushin design group. It was first displayed in July, 1957, at Moscow/Vnukovo Airfield.

The Russians claim that, with a cruising speed of 350 knots at 26,000 ft., the Il-18 will carry 30,800 lbs. of payload for 1,200 nautical miles. Also, at an unspecified but reduced payload, the aircraft will fly 3,100 nautical miles. Further, it is claimed that the take-off run at a maximum gross weight of 127,900 lbs. is only 2,300 to 2,450 ft., and the normal landing roll is 1,650 to 1,950 ft.

The prototype of the Il-18 is powered by four NK-4 turboprop engines of 4,000 e.s.hp. each, reportedly designed by N. D. Kuznetzov. The engines are enclosed in narrow nacelles which are positioned slightly above the wing. It is stated that titanium is used around the exhaust pipes and other hot portions of the engines. The propellers on the Il-18 are four-bladed and reportedly are reversible, full-feathering, and constant-speed. It is claimed that the feathering mechanism employed when an engine stops in flight is automatic if the engine is operating at more than 90 per cent power. A built-in lock firmly positions the propellers to prevent rotation by the wind when the aircraft is on the ground.

The article states that the Il-18 has a trapezoid-shaped wing made up of a center panel and detachable tips. The span is 122.7 ft. The center panel (72 ft. long) has three spars; carries the engine nacelles, main landing gear, and flaps; and is mounted low on the fuselage.

The description indicates that the fuselage is of conventional monocoque construction and is pressurized. The forward section contains the crew area, the wardrobe, baggage, lavatory, buffet-galley, and the forward passenger cabin. The maximum height of the passenger cabin is given as 6.6 ft.; the aisle is 1.6 ft. wide; and there are 15 circular windows, with a diameter of 16 in., on each side of the fuselage. The forward passenger compartment contains two rows of 5-abreast seats, and the main cabin contains 13 rows of 5-abreast seats. It is claimed that each seat weighs only 17.6 lbs. and that they were specially developed by the Ilyushin Design Bureau.

The crew is made up of five men—a captain and copilot, who are stationed in conventional positions; a navigator who sits behind the captain; and a radio operator who sits behind the copilot. The flight engineer occupies a removable seat located in the aisle between the pilots.

A detailed description of the other compartments in the fuselage is given. Their construction appears to be conventional. There is a section 9.7 ft. long immediately behind the crew compartment which contains a baggage hold (247 cu.ft.), a lavatory, and a crew wardrobe. The buffet-galley is located aft of the front passenger cabin, and the passenger comfort area is aft of the main passenger compartment. It contains a wardrobe, lavatories, and the main entrance door. Another baggage compartment is behind this area.

The Il-18, according to Aeroflot, has excellent rough-field operating characteristics; this is attributed to the wide main gear tread (29.5 ft.), multiple wheels, and low landing and take-off speeds. The main landing gear retracts into wells in the inboard engine nacelles, and the nose gear retracts forward into the fuselage. The weight and drag of the nose gear facilitate its lowering.

It is stated that the Il-18 uses both a.c. and d.c. power, d.c. being supplied by eight generators which also supposedly act as starters. The a.c. current is supposedly 400 cycles and is furnished by single-phase 115-volt generators. Energy for deicing the canopy glass and propeller blades is from the a.c. system.

According to the article, there are deicing systems for the wing, empennage, propeller, and propeller hub. These systems are cut off automatically if any part of the deiced surfaces becomes overheated. Light signals facilitate the monitoring of these systems.

The pressurization system is apparently conventional. It is claimed that sea-level pressure is maintained in the cabin up to an altitude of 16,400 ft., and at 32,800 ft., the cabin pressure is 7,870 ft. An air-conditioning system is installed in the Il-18 to maintain a comfortable cabin temperature. This system uses a turbocooler which receives compressed air from the engine.

It is stated that the control surfaces are not powered but are mass balanced, with aerodynamic compensators installed on the ailerons. The nose gear is steerable and is controlled by a star knob in the cockpit.

Equipment, it is said, is operated by both electrical and hydraulic power. The landing-gear retraction system is hydraulically operated, as are the nose-gear steering, the braking system, and the windshield wipers. Hydraulic-system pressure is reportedly 3,000 psi.

Molecular Weights Found Through Use of Gamma Rays

◆ It is reported that Japanese researchers have been able to use the results of gamma-ray irradiation on macromolecular compounds as a means of determining molecular weights, an operation which in the past had been extremely difficult. The work was done in Negoya at the Government Industrial Research Institute of the Agency of Industrial Science and Technology. If the report is valid, gamma irradiation can be used to determine the "exact molecular weights" of such compounds as Teflon and Kel-F.

The effects of irradiation can be related to the alteration observed in such properties as amount of crystallinity, transition heat, specific heat, specific volume, tensile strength, and—by interpolation and/or extrapolation—can be used as a calibration of the substance under examination.

Determination of the exact molecular weight of such macromolecules would permit more accurate control of polymerization, thus producing a definite and purer polymeric compound. This control would determine and improve the physical, chemical, and mechanical properties of the polymer.

The data available are not sufficient to permit complete evaluation of the report at present. However, it is known that irradiation does cause chemical and physical changes in many materials, particularly such organic compounds as polymers.

XUM

GUEST EDITORIAL

The Challenge Is Here—NOW

By L. V. Berkner

At the beginning of the century, man would scarcely have coupled the successful demonstration of practical radio by Marconi with the first flight of the Wright brothers at Kitty Hawk on December 17, 1903. Yet, these two seemingly unconnected lines of development were soon to conjoin to produce the most powerful development of our time—the conquest of the air and the space around us. Within 10 years of Kitty Hawk, men like Hap Arnold were bringing radio and flight together. Thus began a half century of striking development during which electronics has become the eyes and ears—and in fact the central nervous system—of flight in all its forms. Today useful flight operations in the atmosphere and above would be quite impossible without the control and information that electronics can provide.

The vital interdependence of these lines of technology—initially unrelated—in generating so major a consequence as space conquest illustrates a fundamental lesson that no nation can afford to miss. Certainly, Ben Franklin could not have imagined, as he drew a spark from the string of his kite, that he was founding a science that would underlie man's conquest of space. When Michael Faraday noticed the effects of electric currents on a compass, he could only hope that it was an idea "from which some day man could collect taxes." The realization of electrical self-induction by Joseph Henry, the mathematical formulation of electromagnetism by Clerk Maxwell, and the demonstration of electromagnetic waves by Heinrich Hertz could not possibly be related to man's conquest of space by their brilliant progenitors. Fortunately, the growth of man's ability to ferret out and to understand the secrets of nature was not governed in the early days by the need to "relate research to requirements," or the genius of men like these might have been diverted to the invention of better sails for sailing ships, rather than to the generation of the powerful ideas that have had such persuasive influence on our time.

Out of seemingly unrelated researches have been constructed the magnificent foundations for the control of flight. Following rudimentary air-ground communications of the 1920's, a few able men were able to see that useful flight must depend on the potentialities of communications, navigation, and control that electronics could offer. The penetrating imagination of Haraden Pratt in devising the radio range in 1927 provided the opportunity for youngsters like Bill Jackson and me to demonstrate its capability on the

original Hadley-Belle-Fonte-Cleveland airway. The invention of radar by Merle Tuve in 1925 (incidentally, again for the unrelated purpose of detecting the ionosphere) and the successful demonstration of UHF in the early 1930's contributed to the immense influence that electronics was to exercise on the character of flight during World War II. But the whole of this technological explosion grew out of the simple unrelated researches of the last century that had as their only purpose the clear understanding of obscure natural phenomena.

For a nation that would be strong, the conclusions to be drawn are abundantly clear. First, the most important researches with the most significant consequences can rarely be related to "requirements." Such researches arise from curiosity about some unresolved phenomena of nature and from a means of obtaining quantitative and objective information about these phenomena. They arise from the human desire to associate the diverse elements of nature's behavior in an orderly and definable way. Therefore, our national research policy must, *above all*, encourage and support men who are willing and able to ask the most fundamental questions and seek their answers in an orderly way without regard to "requirements."

Second, the gestation time of the really important researches is of the order of a half century from the first observation of fundamental truths to the realization of the emergent technology. This is so long as to be almost wholly unrelated to the investment cycle of our economic system. Consequently, there is no alternative to sources of research support that do *not* depend upon the immediate profit motive. In spite of the magnificent contributions to the advancement of knowledge by our industrial laboratories, the growing cost and complexity of research that cannot be justified by profits foreseeable in the immediate economic cycle make necessary large-scale Government support. Inevitably, costly tools and group effort must be provided if we are to ask of nature some of the most obvious questions that may lead to the most productive technology. In view of our present tax structure, only governments can now provide this support on an adequate scale. Such action is wholly justified by the long-term quality of investment in research and the general benefits to all that emerge from such an investment.

In contemplating the future of space research, we, like Ben Franklin, are helpless to predict where it will lead or what profitable technology will ultimately emerge. But the challenge that nature offers, and that now lies within our grasp, cannot be ignored, for repeated experience has clearly shown that it must inevitably produce great benefits for mankind. As a nation we must seize this new opportunity to exploit the secrets of nature to which there are already abundant clues. The tools of observation are now within our reach; we need only the determination and the imagination to follow through. And when have we ever lacked for either?

L. V. Berkner is President of Associated Universities, Inc., an educational institution sponsored by nine leading universities. Its activities include operation of the Brookhaven National Laboratory and the National Radio Astronomy Observatory. Dr. Berkner is active in organizations of international scientific activity as President of the International Council of Scientific Unions and President of the International Scientific Radio Union, as well as Vice-President of the Special Committee for the International Geophysical Year and IGY Reporter for Rockets and Satellites.

The possible effects of dissociation and ionization behind strong shock waves on stability and guidance of hypersonic vehicles are discussed. The requirements for dynamic and static stability for certain classes of hypervelocity atmospheric entry bodies are described, using examples. A hypervelocity glide vehicle configuration is presented as an illustration of possible future airframe configurations.

Hypersonic Aerodynamic Factors in

Symbols

a = semimajor axis of ellipse (see Fig. 2)
A = reference area for coefficients (base area for bodies)
b = semiminor axis of ellipse (see Fig. 2)
C_D = drag coefficient
C_L = lift coefficient
C_{L_α} = $dC_L/d\alpha$
C_M = pitching moment coefficient
C_{M_α} = $dC_M/d\alpha$
C_{M_q} = $dC_M/d(ql/V)$
$C_{M_{\dot\alpha}}$ = $dC_M/d(\dot\alpha l/V)$
C_N = normal force coefficient
D = drag force
g = acceleration due to gravity
i = static stability parameter (see Fig. 5)
j = drag parameter (see Fig. 5)
k = dynamic stability parameter (see Fig. 4)
l = length of body
L = lift force
N = number of electrons per cm.^{3}
q = flight path curvature rate in rad./sec.
W = weight
α = angle of attack
$\dot\alpha$ = $d\alpha/dt$
θ_V = cone semivertex angle
ω = pitching oscillation rate (see Fig. 5)

THE ERA OF hypervelocity vehicles is clearly upon us. Numerous military and scientific projects—including, for example, ICBM, IRBM, X-15, X-17, and earth satellite projects—serve to illustrate this. In the design of such vehicles, recourse is made to a relatively new realm of aerodynamics—hypersonic aerodynamics. An effort will be made here to examine the possible interplay of certain aspects of hypersonic aerodynamics with problems of stability, performance, guidance, and control.

Generally we shall be concerned herein with vehicles which fly through or in the atmosphere at Mach Numbers in excess of about 6. It is at and beyond this flight Mach Number that the effects of the "real gas" nature of air begin to appear in the aerodynamics of a vehicle and the methods of conventional aerodynamics begin to lose some of their validity.

Such vehicles generally fall into two broad categories—earthbound vehicles including glide, skip, and ballistic vehicles[1] and vehicles with the primary function of penetrating and/or exploring space.[2] Most of what will be discussed here is concerned primarily with earthbound vehicles.

Glide Vehicles

The long-range hypervelocity glide vehicle has been shown to be a competitively efficient long-range device.[1] Such vehicles, depending as they do on aerodynamic efficiency, may possibly employ lifting surfaces for stability and control. In order to assess their stability and controllability properly, the conventional aerodynamic coefficients must be determined in the hypersonic flight regime. What possible unique problems arise?

One such problem is the possible effect of excitation of the higher modes of the air molecules as they pass through strong leading-edge shock waves on lift force coefficients. For example, if vibration and dissociation of the diatomic molecules, ionization of the diatomic molecules and atoms, and formation of new compounds occur in the hot gas, how does this affect normal force coefficient and, indirectly, stability or controllability?

Logan[3] investigated this, drawing upon recent experimental results. He suggested, for lifting surfaces having an initial region of compression in the bottom surface followed by a region of expansion (such as the double-wedge airfoil shown in Fig. 1), that there may indeed be some uncertainty as to the lift force coefficient. He speculated that the air in the compression region (region 2 shown on Fig. 1) will probably be in its equilibrium high-temperature state within a few

Mr. Dorrance is Assistant to the Director of Scientific Research, San Diego, Calif.

Performance, Guidance, and Control

William H. Dorrance
Convair, A Division of General Dynamics Corporation

mean free paths behind the shock wave. However, there is some question as to whether the air adjusts ("relaxes") rapidly to its equilibrium state upon expanding around the corner into region 3 shown in Fig. 1. Experimental data suggest that there may be regions of flight where the air does not reach its final equilibrium state in region 3, and hence the pressure on the lower surface of such an airfoil in the region of expansion will be uncertain. The resultant possible uncertainty in normal force coefficient of a double-wedge airfoil at Mach 20 and 120,000 ft. is shown in Fig. 1. The equilibrium normal force coefficient was taken from reference 4, and the approximate correction for possible nonequilibrium flow conditions in region 3 was taken from reference 3.

A desirable hypervelocity glide vehicle configuration should have a high value of maximum lift to drag ratio to maximize range for given initial velocity[1] and, further, should have a high lift coefficient at maximum lift to drag ratio. This latter quality is desired to enable the glide path to be as high in the atmosphere as possible for a given wing loading in order to minimize the possible severe heating problem. Other desirable characteristics include low leading-edge heating and favorable low-speed qualities if the vehicle is to be landed.

Intrigued by the possible favorable characteristics of the delta wing configuration at hypervelocities, the author initiated a study of elliptic cones late in 1951. This work demonstrated in theory that elliptic cones did indeed possess desirable glide vehicle aerodynamic characteristics at hypervelocities.[5] Recent tests at Mach Numbers 1.97 and 2.94 reported in reference 6 tend to bear this out as can be shown using Fig. 2.

Shown on Fig. 2 are curves of measured maximum lift to drag ratio and lift coefficient at the angle of attack of maximum lift to drag ratio plotted versus the ratio of major axis to minor axis of the elliptical cone cross section. It can be seen that, as the eccentricity of the cross section increases, the two aerodynamic parameters improve.

Also shown in Fig. 2 is a schematic of how such a configuration might be modified for use as a hypervelocity glide vehicle. The tip would be rounded off to alleviate the heating problem there. To avoid the control surface difficulties presented by thin aerodynamic surfaces, flap-like, hinged, surfaces could be projected in both the pitch and yaw planes as required. No regions of expansion on the lower surface, such as

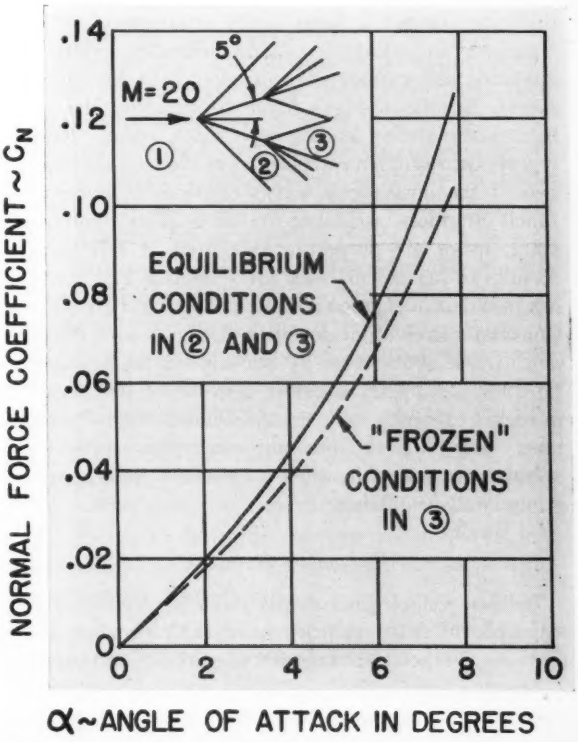


FIG. 1. Approximate effect of recombination relaxation upon airfoil normal force coefficent at Mach 20.

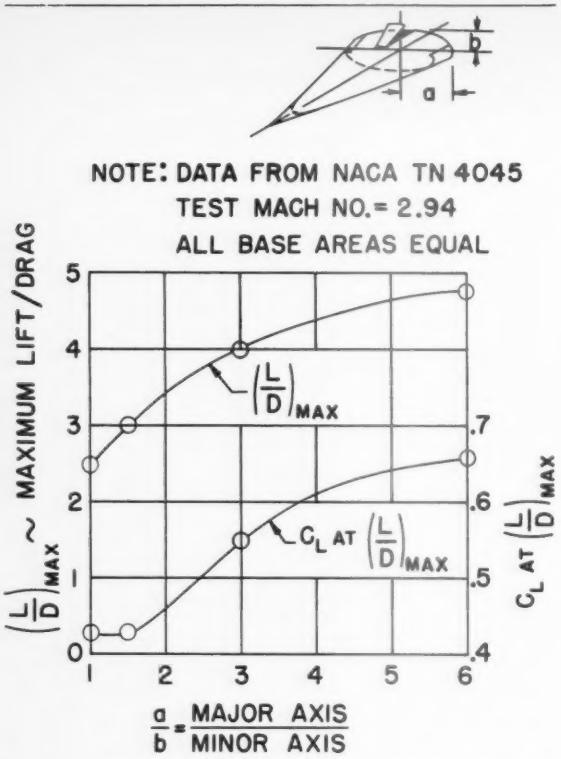


FIG. 2. Illustrated superiority of elliptic cones as glide bodies.

are present on wings as shown in Fig. 1, would present themselves.

Another, possibly more serious, difficulty presents itself for vehicles in flight in the atmosphere at Mach Numbers exceeding 10. This difficulty, related to guidance and communication, is that of the electron density in the hot gas layer surrounding the body behind the strong leading-edge shock wave. Romig[7] reports the results of calculations of the electron density behind the nose shock waves of cones at hypersonic Mach Numbers, assuming the air is in its equilibrium state, using air properties tabulated in reference 8. Results of her calculations are shown in Fig. 3 where electron densities greater than 10^{10} per cm.^{3} are shown. Contrast the electron densities of Fig. 3 with electron densities of about 2 by 10^5 per cm.^{3} in the ionosphere (20 to 80 km.) and maximum densities of 10^{13} per cm.^{3} in rocket exhausts, and the significance of this becomes more apparent. Radio communication between a vehicle surrounded by such an electron cloud and the ground may be difficult.

BALLISTIC VEHICLES

Ballistic vehicle final stages and other hypervelocity atmospheric entry vehicles have their peculiar aerodynamic characteristics related to guidance and control.

Among these is the oscillatory pitching motion experienced by a hypervelocity entry body if it enters the atmosphere at an angle of attack. Friedrich and Dore were among the first to study this problem.[9] They examined the effect of drag and aerodynamic stability of the entry vehicle on the resultant pitching motion. It was shown that, for certain combinations of drag coefficient, lift coefficient slope, and damping coefficient, a divergence of the pitching amplitude could occur following an initial convergence during descent through the atmosphere. Such a situation would call for automatic stabilization or programed control forces if such a divergence is to be avoided.

Allen examined this problem, and others related to it, in considerable detail.[10] Fig. 4, taken from reference 10, shows the effect of a static stability parameter k on the pitching amplitude envelope during hypervelocity descent. It is seen, upon examining Fig. 4, that, for positive values of the parameter k, a divergence could occur.

The analyses of references 9 and 10 bring out another difficulty associated with hypervelocity entry. Related to this possible oscillatory pitching motion is the frequency of motion. Fig. 5, taken from reference 10, shows maximum pitching frequencies during atmospheric entry for several example bodies entering the atmosphere at 20,000 ft./sec. at nonzero angle of attack. Note that these maximum frequencies range up to 10 cps. Such pitching oscillations can be disturbing to pilots, guidance systems, and fusing devices if allowed to persist and present a challenge to entry vehicle autopilot synthesizers.

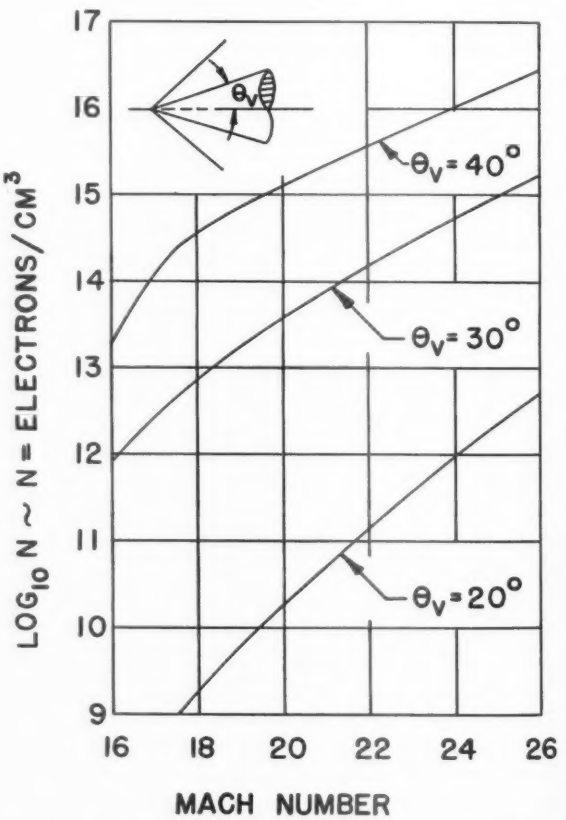


FIG. 3. Electron density behind cone shock wave at 51,000 ft. altitude.

Aerodynamic Heating

No mention of the problems of aerodynamic heating of hypervelocity vehicles has been made here. Excellent résumés of the design problems created directly by the high aerodynamic heat transfer exist in the literature. See, for example, references 1 and 11. However, no discussion of the relation between hypersonic aerodynamics of high-speed vehicles and guidance and control problems would be complete without pointing out the effects of hypersonic boundary-layer heat transfer.

Because of the high heat transfer associated with hypervelocity vehicles, all surfaces exposed to the boundary layer can get very hot depending on the thermal protection system used. Probably insulating materials will be used to protect glide vehicles which may be able to back radiate a significant portion of the heat transfer. Ballistic and other atmospheric entry bodies will probably mostly rely on heat sink materials and other heat absorbing schemes. Few of these thermal protection artifices make allowances for desirable radome characteristics or allow electromagnetic wave propagation through them without considerable attenuation.

Hot control surfaces tend to warp and bind at high temperature. This again presents a serious problem to the vehicle designer. No doubt, hinge lines will tend to be avoided by using unconventional control devices.

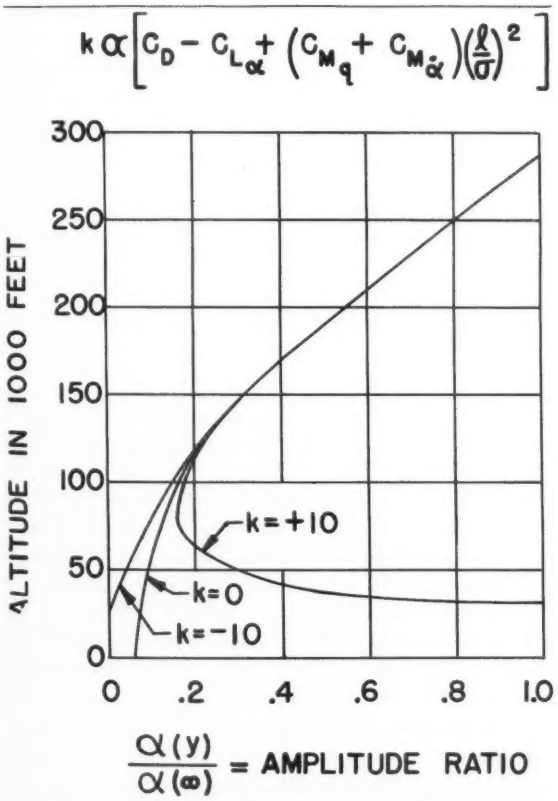


Fig. 4. Effect of stability parameters upon pitching amplitude for hypersonic atmospheric descent.

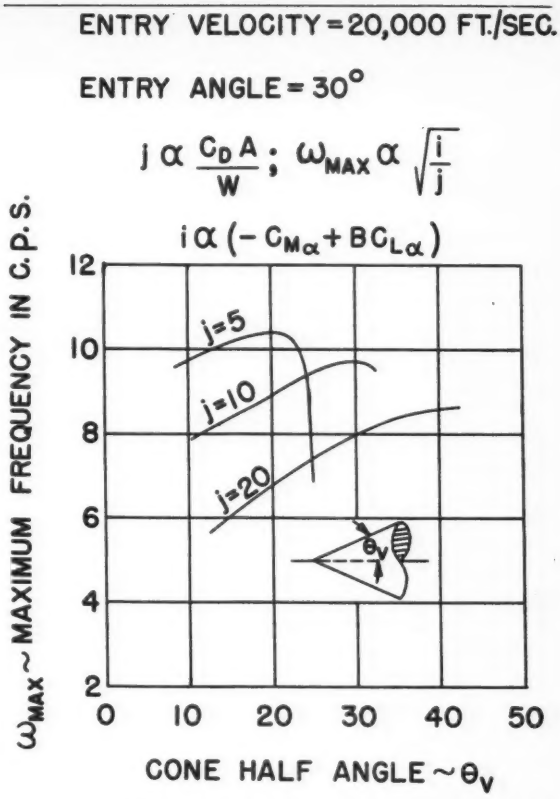


Fig. 5. Maximum pitching frequencies of cones entering the atmosphere at 20,000 ft./sec. and nonzero angle of attack.

Conclusions

Some of the aerodynamic factors in hypersonic vehicle design related to guidance, navigation, stability, and control have been briefly discussed here. Based on the material presented one might conclude:

(1) Stability and performance coefficients in the hypersonic flight regime may be uncertainly estimated because of the uncertain state of the knowledge of the behavior of high-temperature air.

(2) However, vehicle configurations can be envisioned which minimize the uncertainty referred to in Conclusion (1).

(3) A serious communication problem may arise owing to the high electron density which may exist in the hot gas surrounding a hypersonic vehicle.

(4) Hypersonic atmospheric entry vehicles may require automatic control during descent to achieve pilot comfort, guidance, and fusing system accuracy.

(5) Thermal protection systems for hypervelocity vehicles may not be well suited to radome and electromagnetic wave propagation.

References

[1] Eggers, Alfred J., Allen, H. Julian, and Neice, Stanford E., *A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles*, NACA TN 4046, October, 1957.

(*Continued on page 43*)

Edward G. Schwarm
Link Aviation, Inc.

Electronic Simulation for the Jet Age

"A typical airline training program for an eight-aircraft jet fleet can show a net savings of $2,192,000 over a 10-year period by using a simulator to replace half of the actual flight time."

With the introduction of jet aircraft into the commercial aviation field, many new problems will arise. Navigation at high speeds and long ranges will require new techniques, while accurate cruise control will attain a new order of importance. Bringing these aircraft from high altitudes into crowded approach areas at high speed will require precise coordination. Such problems will place heavy demands on flight crews and control centers. Extensive training will not only be desirable—it will become essential.

Previously, most training had been done in actual aircraft. Because of the large investment represented by each new jet transport, it is a pressing matter of economy to place each one in operation as soon after procurement as possible. To accomplish this, the use of precision operational flight simulators becomes a virtual necessity. Today simulators are being built in advance of actual aircraft delivery and, in some instances, actually in advance of the first flight of the prototype aircraft.

Economics

The economic advantages of flight simulators for airline training in reciprocating engine transport aircraft have been well established.[1] These advantages are even more pronounced for jet transport training. By means of a carefully planned operating and maintenance program, a utilization of 330 hours per month can be achieved.[1] It has been estimated that the cost of operation of a modern jet transport simulator will be $29.27 per hour.[2] A typical airline training program for an eight-aircraft jet fleet can show a net savings of $2,192,000 over a 10-year period by using a simulator to replace half of the actual flight time. These savings rise to $8,642,000 for a similar period with a 30-aircraft jet fleet.[3]

Mr. Schwarm is a Project Manager.

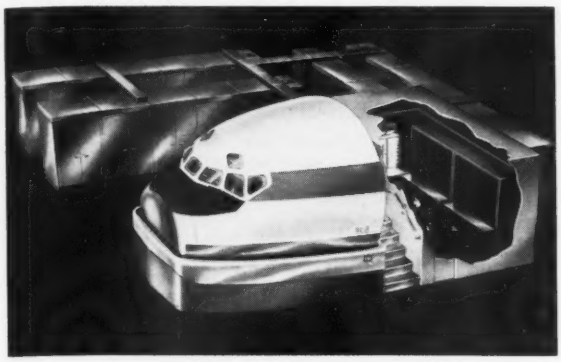
The Simulator

An electronic operational flight simulator consists primarily of a cockpit section which is a replica in every noticeable detail of the interior of the actual aircraft being simulated and a special-purpose analog computer to solve the necessary aircraft and navigational equations. Complete and accurate simulation of all phases of the aircraft equipment is required for satisfactory training. By proper instructor action it is possible to introduce appropriate and realistic failures and malfunctions into the various aircraft systems. In this manner, a high level of crew training and coordination can be obtained, as many of these failures cannot be introduced into the actual aircraft at will. Other failures would expose the crew and aircraft to undue hazard. In normal operation one or more flight instructors accompany the crew in the cockpit section while the radio aids operator operates the ground navigational equipment and acts as the ARTC controller.

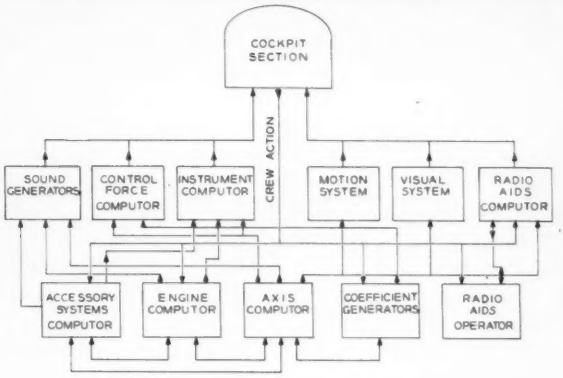
Flight Computer

The heart of the flight system computation is the axis computer. This computer solves the nonlinear equations of motion for a six degree of freedom system. For instrument read-out, position determination, and coefficient generation it is necessary to obtain data in the aircraft, wind, and stability axes. A further axis transformation is necessary to convert aircraft velocities as computed along the wind axis to earth axis velocities for the purposes of determining ground position, track, and altitude.

All appropriate aerodynamic coefficients are generated in the coefficient computer section. These coefficients are generated in complete nonlinear form by means of servo and diode function generation. To enable use of the operational flight simulator before



Artist's conception of DC-8 flight simulator.



Data flow diagram of DC-8 flight simulator.

actual aircraft flight, the basic data for coefficient generation are obtained from design, estimated, and wind-tunnel data. The effects of Mach Number and aeroelasticity are fully considered.

Accurate primary control force computation is, of course, essential to satisfactory simulation. Various schemes of artificial control loading have been employed in the past, but the most feasible of them appears to be a high-performance force sensitive hydraulic servo, one for each of the control axes. In this scheme a double-acting hydraulic cylinder is connected through proper linkages to the appropriate control. A high-speed hydraulic servo valve controls the cylinder fluid flow. By placing a force measuring transducer in the control linkage, it is possible to measure the actual force existing. A position transducer on the control loading unit feeds data to the coefficient computer. This, in conjunction with information received from the axis system computer, provides the necessary data to compute the control force desired for a given control position. By comparing this desired force with the force existing as measured by the force transducer, the hydraulic servo valve may be correctly positioned to give the correct force on the control column.

Engine Computer

As most turbojet engine data are readily available in a form in which thrust, exhaust temperature, and fuel flow are expressed in terms of engine pressure ratio, pressure ratio becomes an attractive independent variable to use for the purposes of computation. Engine r.p.m. is computed as a function of throttle position and other appropriate parameters dependent upon the individual engine regulator system. By proper reduction of data, it is possible to express engine pressure ratio as a function of two independent variables, engine r.p.m. and ram air temperature. The appropriate steady-state values of fuel flow, thrust, and exhaust temperature can then be computed by straightforward function generation using engine pressure ratio and other parameters as independent variables. While thrust follows pressure ratio quite closely during accelerations and decelerations, fuel flow and exhaust temperature vary quite widely. It has been found practical to consider the incremental differences of these functions between the steady-state conditions and the values obtained under conditions of jam acceleration and deceleration These increments may be reduced to functions of r.p.m. and altitude. It is then only necessary to determine when the engine is being accelerated or decelerated and add these increments to the steady-state condition. The end result is realistic operation during rapid change with a very accurate computation under steady-state operation.

Accessory Systems Computer

Accessory or ancillary systems such as electrical, hydraulic, pneumatic, de-ice and anti-ice, cabin pressurization, control boost, etc., comprise a major portion of a modern jet transport aircraft. While many of the operations may be represented as switching functions using relays to perform the computation, others require a considerable amount of arithmetic operations with appropriate time constants applied. It has been found, for example, quite feasible to represent the electrical system by means of a complete analog which includes each bus in the system with its appropriate inputs and outputs. These values must be computed in an accurate quantitative manner to provide proper system operation and instrument read-out. All switches, circuit breakers, and fuses accessible in the flight compartment must be connected into this system and operable. Electrical loads must be computed and applied to the proper buses for complete simulation. Each valve, pump, and actuator in the hydraulic system must be represented by its equivalent electrical analog. Appropriate hydraulic line losses must also be included to provide correct pressure readings and indications of operation of the various components. The fuel system must be analoged in a similar manner. Line losses, effect of fuel quantity in each tank, and airplane attitude upon pumping head must be computed to obtain fuel pressures.

Instrument Computer

The primary purpose of the aforementioned computation is, of course, to provide correct instrument presentations to the pilot and other crew members. Aircraft instrumentation has been vastly improved in recent years with errors being reduced considerably. This simplifies the problem of instrument simulation under normal operating conditions. However, some instrument systems still have inherent time lags and errors which must be accurately simulated, while computation must be employed for other instrument systems to furnish appropriate readings under abnormal conditions and simulated malfunctions. It has been found generally feasible to apply correct basic data to a separate instrument computer peculiar to each instrument system. In some cases, it is practical to compute the instrumentation errors and apply these in arithmetic form to give the final instrument presentation. In other cases it is more practical to completely analog the instrument system and apply correct data to this analog, allowing it to compute its own errors.

To complete the illusion of flight, the sounds encountered in the actual aircraft must be simulated. These sounds generally fall into two categories—those of a random nature, such as slipstream noise and jet exhaust, and those employing a definite frequency component or a series of components such as turbine whine, hydraulic sounds, and cabin air compressors. Random type sounds are produced from a gas tube white noise generator. Proper filter networks are used to provide the desired frequency spectrum for each particular sound. To produce those sounds which contain discrete frequency components, variable frequency oscillators are used. The frequency and volume level of these sounds are controlled directly by the computer sections to provide coordination between actual flight operation and sound. A trinaural sound system is used with speakers located in the nose and left and right sides of the simulator cockpit.

Radio Aids

All radio controls and indicators are installed in the simulator cockpit section in the same manner as they would be in the aircraft. The radio aids computer, by taking information from the axis system computer, continuously determines the altitude, bearing, ground range, and slant range from the simulated aircraft position to each of six simulated radio stations. These stations are located by the radio aids operator and used to simulate actual stations in both type and location, as shown on the standard aeronautical maps. By simple selection, any of the six stations may be set to represent any standard type of aeronautical navigation station. The call signals for these stations are generated by electronic keyers which may be set to produce any of the standard three or four letter codes now in existence. Once set up, the operation of these stations is entirely automatic. The position of the simulated aircraft is displayed by means of a rectangular coordinate recorder which indicates the ground path overlayed on an aeronautical map showing the location and types of radio facilities being used. An auxiliary recorder shows an enlarged view of the area around any selected radio station. This recorder is used primarily for approach and local area flying. An altitude deviation recorder shows the altitude deviation from glidepath for a final approach using an ILS or GCA facility.

Visual Approach System

As present equipment limitations require that the pilot must make his actual landing and take-off with visual reference to the ground, a visual system has been developed to provide this training in the simulator. While the visual system is, in itself, a relatively complex device it can be briefly described as follows:

A very accurate model of the actual airport runway and its approach area is constructed to scale. By scanning this model with a television camera located to represent the pilot's eye and projecting this image on to a large screen mounted in front of the cockpit section, it is possible for the pilot to make simulated visual landings with a startling degree of realism. By assuming that the pilot's eye moves with the aircraft at all times, it is possible to supply data to the television camera from the axis system computer. The camera system must be capable of reproducing the six degrees of freedom of the aircraft. Longitudinal translation is accomplished by having the camera mounted on a carriage which moves along a track parallel to and above the runway. Lateral translation is accomplished by moving the camera transversely on its carriage. Aircraft altitude is simulated by raising or lowering the camera with respect to the runway model. The camera is mounted with its optical axis vertical to the runway. By means of a rotatable mirror mounted at approximately 45° to the optical axis and directed approximately down the runway, it is possible to simulate pitch of the aircraft by rotating the mirror about a pivot parallel to the aircraft Y-axis. Heading change is accomplished by rotating the mirror and camera about an axis perpendicular to the runway surface. Roll of the simulated aircraft is accomplished by rotating the camera about its own optical axis. All degrees of freedom are controlled by electrically powered high-precision servos. Sufficient depth of field can be obtained with this system by using a small lens opening and adequate illumination to provide a sufficiently strong image on the camera tube.

The visual system provides a realistic and appropriate beginning and end to a simulated flight.

Motion System

The "feel" of the accelerations of roll and pitch, while not reliable sources of information in actual aircraft instrument flying, do supply cues that are most important. To provide these data, a two-axis motion system operated by high-performance hydraulic servos

is used. By pivoting the cockpit section with a universal joint at the rear, it is possible to obtain necessary roll and pitch effects and simulate various sources of vertical accelerations for limited periods of time.

The roll axis position is determined by two primary inputs, ball position and bank angle. Upon entering a coordinated turn, the cockpit rolls with the bank angle of the simulator. To avoid the feeling of an uncoordinated turn, the cockpit recovers to a level position at a rate imperceptible to the pilot. Upon recovery from the turn, the cockpit rolls in the opposite direction and then slowly recovers to the level position. In this manner, roll accelerations, so important as pilot cues, are transmitted physically to the pilot.

The actual pitch angle is presented as the pitch of the cockpit. By nonlinear control it is possible to obtain sensitivity for small pitch angle changes without exceeding system limits at large pitch angles. The vertical accelerations of rough air are fed to the pitch axis in the same direction and proportionally to the inputs supplied to the flight computers. Nonlinear control is once again used to obtain maximum effect. The various longitudinal accelerations are represented by pitching up or down to give the effect of rotation of the apparent g vector. High-speed and stall buffet effects are realistically presented with their effects slowly becoming more evident as the buffet boundaries are approached.

Simulator Utilization

The primary use of the flight simulator by airlines is in crew training under carefully controlled conditions. A crew briefing is held by the flight instructor to cover all details of the proposed simulated flight. The flight is then carried out in the simulator in accordance with these instructions. All flight and navigational procedures are followed in the same manner as they would be under actual flight conditions. The flight instructor accompanies the crew in the cockpit section. In addition to instructing the crew, he gives operating instructions to the radio aids operator and inserts troubles and malfunctions into the simulator at appropriate times. For certain operations a flight engineer instructor is also carried in the cockpit section. After the simulated flight, a debriefing session is held in which various aspects of the flight are discussed and corrective instruction given. The simulator is also used for transition training, primarily on an individual basis with the flight instructor acting as the other crew member.

The Douglas Company has recently purchased a DC-8 flight simulator for its own use. The first application will be in the training of Douglas flight-test crews and their airline customers prior to actual flight in the DC-8 aircraft.

Another will be used by the Engineering Division for studies in the areas of performance, stability, and operation. The simulator can be modified quite readily to install experimental equipment for feasibility studies without the expense of installing and testing this equipment in the actual aircraft.

The simulator will also be used for human engineering studies. Readily installed instrumentation permits very accurate monitoring of all control operations during a prescribed problem, thereby furnishing complete human factors information for present and proposed control arrangements and systems.

In addition, the flight-test group will use the simulator for rehearsal of certification flights.

Conclusion

The use of the operational flight simulator to promote higher crew efficiency and safe airplane operation is well established. The economic advantages of using simulators to augment actual flight time are well known and constitute the primary reason for their rapid integration into airline training programs. The use of a flight simulator by an aircraft manufacturer will enable him to shorten appreciably the time from design to certification. Now well-established in aviation, the flight simulator will continue to increase in usefulness as newer aircraft become larger, fly faster, and require more skillful and better-trained crews.

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(See page 71 of this issue.)

Krafft A. Ehricke
Convair, A Division of General Dynamics Corporation

OUR PHILOSOPHY OF Space Missions

*"Do not undertake vast projects with half vast ideas"**

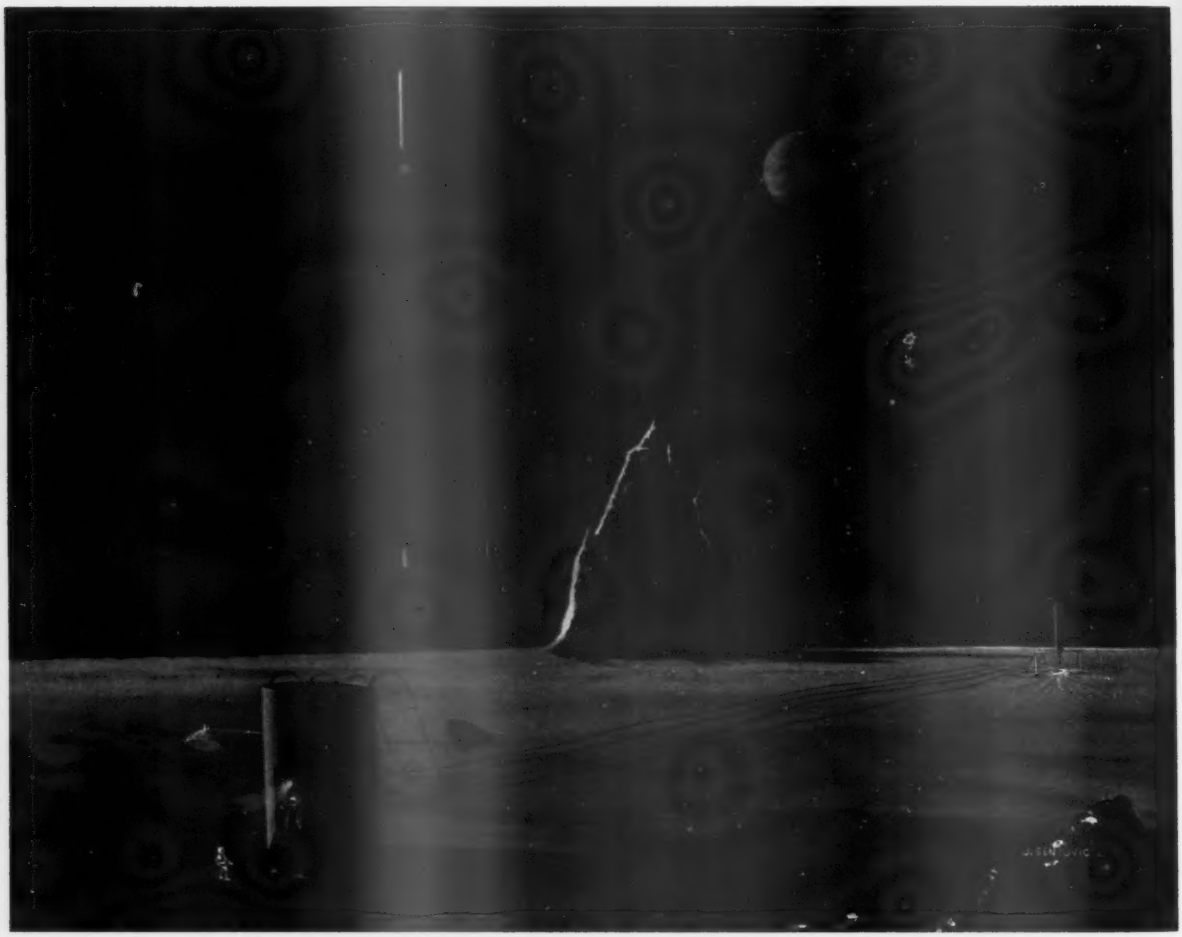

FIG. 1. On the moon, one nuclear-powered spaceliner is shown with its crew debarking while a second prepares to alight (*left background*). Mild thrust counters lunar gravity and the rocket is "backed down" until the gondola rests on the surface. The power plant is landed nearly 1,000 ft. distant at the limit of connecting cables for protection of personnel from radiation hazards. Communication with earth (*upper right*) is possible by microwave radio. This spaceliner would carry a 15,000-lb. payload to the moon with sufficient fuel to take off and return to a position just outside the earth's atmosphere.

The author is Assistant to the Technical Director, Astronautics Section.
Drawings by John Sentovic, Convair.

*** Contributed by Pete M. Suarez to *Readers Digest*, January, 1958.**

FIG. 2. Depicting sunrise departure of five chemonuclear spacecraft from the earth nonstop to another planet. Light from the engines of four appear as streaks in the sky. After they depart, the manned flagship follows (*foreground*) from a water-based launching pad. Such flights can be attained by a chemical and nuclear-heated drive in two successive stages.

AFTER A PERIOD of reluctance and doubt as to the national importance and utility of space capability and concern lest we be lured into expensive space ventures, a limited effort was authorized for several small scientific satellites in the framework of the International Geophysical Year. President Eisenhower's historic decision of July, 1955, probably not only started our own efforts but most likely also accelerated satellite preparations under way in the Soviet Union. There, the whole weight of a decade of military missile development was thrown into the game, partly probably for sheer economic necessity, partly to avoid being beaten in the final phase of a long and consistently pursued program. The impact of the first satellite—an effect whose possibility frequently was denied before—may have surprised even the Russians. Meanwhile the United States has launched successfully three satellites. Numerically, the orbit game stands 3:2 for the U.S.A. at the end of March. In terms of astronautical capability, the U.S.S.R. still holds the undisputed lead. It has been stated that, had *we* successfully launched the first satellite, the world would perhaps have been less surprised. However, even in absence of a surprise element, our accomplishment would have created the same worldwide acclaim, not only as an individual performance but at least as much because of the potential implied.

What is this potential and how real is it? The correct answer to this question presents an important problem because some people keep telling us that we cannot undertake everything that can be done in space flight (which, incidentally, nobody has ever suggested, and which is overcautious advice, to say the least, after we have been careful to spend as little as possible for space flight). Clearly, the potential implied by orbital capability lies in three major areas: the *psychological effect* of technical and scientific leadership in the ideological struggle between democratic and communist forms of civilization; a *hard and cold military potential* through the use of space; and finally, the implications of *increased scientific knowledge* through space exploration. This promises to yield not readily defined but not necessarily inconsequential utilities, much as exploration of the unknown has done in the past.

XUM

Psychological Potential

Psychological effects are intangible but very real. In the present ideological struggle, they can obviously be produced by a variety of accomplishments, not only in the field of astronautics. It should not be necessary to emphasize that even the "prejudiced" protagonists of space flight are capable of understanding this fact. To some degree, their concern for a concentrated astronautic effort is based on the understanding that the cold war is fought on more than the military, economic, and political front, and that, by neglecting accomplishments in astronautics, an important sector on the psychological front is neglected also. That the psychological effect of space capability is a powerful one has been proved nowhere more convincingly than in this country following the U.S.S.R. satellite launchings. Applications previously regarded with great skepticism—such as propaganda shots to the moon, orbital stunts as well as quick launchings of humans, and propaganda broadcasts from satellites—are suddenly discussed seriously as possible next actions of the cold war in space on both sides of the iron curtain. However, psychological effects work both ways. The blow has been hard to us because we took our technical superiority for granted, although we should have known better in view of earlier Soviet accomplishments and of their scientific talent. Communism attaches great significance to techno-scientific leadership for the sake of survival and power of its own system, as well as for internal and world prestige. Therefore, the psychological impact of a defeat in this field, or even of a lack of superiority, must be strong, especially if it occurs in an area in which leadership finally has been won in recent times. Space capability is one of these areas. We may indeed assume that the psychological potential of superior, or at least not inferior, space capability is real and important in the future.

Military Potential

The military potential of space capability is quite tangible in terms of this nation's defense and the survival of western civilization. This certainly is true for quasi-space weapon systems, such as the IRBM and ICBM, whose brief stay in space is coincidental relative to the significance of the location of their launching sites (land-based, water-based, air-based) or their storage and launching on the surface of the Earth. However, this is also correct for true space weapon systems which derive their military value from their existence in space. Military space capability, or control of space, is a new concept subject to various interpretations. It is trivial to say that space control does not mean actual physical control of all motion in, and all access to and from, space. Britain never controlled the seas in this sense. Much less will any nation ever exercise such dominating control over space short of subjugating all other nations on Earth first. A more realistic interpretation of space control implies that we must be at least as capable as any other nation to (1) operate weapon systems in space with missions pertaining to the Earth's surface, and (2) conduct Earth-to-orbit and orbit-to-orbit warfare, both in the defensive and offensive sense of the term. Whether a space weapon system becomes more or less effective as it operates at increasing distance from the Earth cannot be decided on a dogmatic or principle basis. It depends entirely on the particular circumstances—now, or in the future. Deep-space warfare is a frightening and, to us, still somewhat fantastic prospect. Unfortunately, its possibility is not inconsistent with the pattern of human behavior, given the proper motive. Technically and politically it is not imminent. Obviously, we will not extend military action further out than we have to, and neither will any other nation. The key is in the definition of "have to." Who is to say today how far out we may eventually have to go? The analogy with developments in aerial and missile warfare suggests itself. As far as our military space capability is concerned, the important thing to understand is to be ready to counter an important enemy move *anywhere*, and, if possible, to be ahead of him so as to be better able to anticipate what he might do. The emphasis here is on "capability." The point is not that we should diffuse our strength by undertaking every project that can be undertaken. The point is that we should concentrate our strength by attaining the capability of doing what is necessary when it becomes necessary. Civilizations stand and fall with this kind of capability. The way of attaining this capability can be chosen wisely and in a balanced manner. But it does not reflect balanced thinking to ridicule the possibility that, for example, a lunar base may become of military importance. Fortunately, in astronautics, the energy levels of a lunar landing and an interplanetary flight are much closer than those of a subsonic and a supersonic airplane. For example, a surface-to-surface flight from Earth to the moon (Fig. 1) requires roughly 50,000 ft./sec. (including all losses) or close to 70,000 ft./sec. with return into an Earth satellite orbit. A fast round trip (1 year) to Mars (no landing) from and to an Earth satellite orbit "costs" about 70,000 ft./sec. or about 100,000 ft./sec. if starting from the Earth's surface (Fig. 2) (these numbers representing the sum of all velocity changes during the flight plus all the losses). Similar values apply for flights to Venus. Thus, the energy ratio is of the order of $(10/7)^2$ or about 2. On the other hand, the energy ratio between an $M = 2$ supersonic airplane and an $M = 0.5$ subsonic airplane is roughly 16. Thus, by attaining the capability of flight from the Earth's surface to the moon's surface and return into an Earth satellite orbit, we have, for all practical purposes, attained at the same time the capability of operating in the entire inner solar system since even a flight to Mercury can conveniently be handled with 100,000 ft./sec. If we concede the possibility that we may have to have this lunar capability, it is unrealistic to get excited about a flight to Venus or Mars. We may not undertake such a flight if we are very economy-minded taxpayers and refuse to throw in a $5.00 bill per taxpayer during a given year, but at least we have the

capability of doing so if and when it becomes necessary if we develop our Earth-moon potential correspondingly. The minimum payload requirement for an interplanetary operation is of course greater than for a lunar flight. But in space technology this affects only the number of vehicles to be launched for the mission and does not require a costly new vehicle development. Obviously, a flight to Venus or Mars has no direct military significance, and, to my knowledge, nobody has ever attempted to sell interplanetary operations on the basis of present or near-future military significance. The instrumented satellite became a potential space weapon system as soon as it was established that such a vehicle, through optical and electronic reconnaissance, could render valuable assistance in conducting warfare against a potential terrestrial enemy. The same criterion must be kept in mind when considering the possibilities of other space weapon systems. Warfare is directed in the ultimate analysis against enemy-held territory. Therefore, an antagonist will attempt to control all territory or space (air or vacuum) from which war can be waged against enemy strongholds. Obviously then, he will not move away from the enemy but attempt to approach him under conditions of superiority. For this reason, unless the enemy makes it a stronghold, there would at present be no need to control cislunar space or the moon. But there is a need to control, if possible, the outer air space and the vacuum space in the vicinity of the Earth. Part of this can be done by the instrumented satellite, but this system has a lower altitude limit and does not appear to be a practical offensive weapon system. Satellites in orbits half way to the moon or beyond will not be able to contribute much, if any, reconnaissance information. However, our optical and electronic capability indicates that reconnaissance satellites could be a useful type of space weapon system up to a few Earth radii distance. In fact, such distance offers certain types of advantages over satellites at lower altitude. On the other hand, the race between aircraft and antiaircraft systems could eventually "squeeze" the airplane into the hypersonic superaerodynamic region of operation. That is, it could lead to the rocket-powered, manned, hypersonic glide bomber operating in the upper chemosphere (240,000 ft.) at near-circular velocity for a large portion of its glide path or to the satelloid—i.e. the thrust-sustained satellite—flying in the region of 350,000 to 400,000 ft. Technologically, these systems have all the characteristics of manned temporary satellites, the first step toward manned spacecraft. Militarily, the manned satelloid and temporary manned satellite would constitute a reconnaissance system which for several reasons is more flexible and less vulnerable than permanent satellites (manned or unmanned) because the orbit cannot be precalculated by the opponent like the stable orbit of a permanent satellite and because the presence of human judgment is likely to lend more reliability and operational sophistication to the space weapon system. Thus, the gradual transition from air weapon systems to terrestrial space weapon systems and their antiweapon systems looks like an imminent development during the coming decade. Since there is little we can do about this trend, we might as well direct it.

There is a second important aspect to the military potential of space flight which has to do with the fact that presently we have very little knowledge of the significance which our moon may attain in the future. In spite of its nearness, our satellite is still shrouded with secrets. Will we stand idly by while other nations, above all, the U.S.S.R., proceed to explore the moon's surface and evaluate its possible military and other utilities? Without being able yet to appraise the military value of a lunar base with finality, it must be said that we cannot afford not to find out. The least we can gain is scientific knowledge. Civilization at the end of this century may not find any of our present criteria to be decisive in determining the value and importance of our neighboring worlds.

Scientific Potential

This brings us to scientific knowledge, the third and most important long-range potential of space flight, encouraging maturity and peace. The scientific value of Earth satellites, long ago predicted, has been proved meanwhile by the missions of the Sputniks, Explorers, and Vanguard. Many additional scientific applications connected with more advanced instrumentation, especially optical and television equipment, can be expected in the near future. The observation of the universe in the deep ultraviolet light in which most of the matter radiates opens a completely new cosmos to man. Efforts to observe and understand this cosmos need, for any civilized person, no further justification than that of the enormous scientific importance of this possibility. Of similar significance is the search for life on other planets since for the present we have no empirical foundation for generalizing our biological knowledge knowing life on only one planet. One may not care for bugs from other planets, but the bug is only a symbol for basic research, like the green grass on Earth. This country has been somewhat late, collectively speaking, in appreciating the value of basic research. Criticism voiced on scientific education is in part because of the fact that many young people have been led to be interested in the exploitation rather than in the contribution of scientific knowledge. Contribution always requires some form of sacrifice. Those who cannot contribute directly should at least be willing to do so indirectly. Looking at the recent advances in Soviet science, in the nuclear, astronautic, and many other important fields, it becomes apparent that the Russian citizen must have sacrificed more heavily for his scientific progress than the American citizen ever has. It is not enough to produce scientists. Once we have them, will we be willing to foot the bill for their work which, if they really are scientists, will consist in caring for the green grass of Earth, another meson, the artificial production of a virus, the functioning of our brain, Lyman Alpha radiation from a

TABLE 1
Five Steps in the Development of Space Capability*

Step	Vehicles	Thrust (lb)	Payload capability (lb)				
			Earth Orbital	Lunar Circumnav.	Lunar Satellite	Lunar Landing	Orbit of Venus, Mars
1	Jupiter C; Vanguard	Ten Thousands	Tens	-	-	-	-
2	Jupiter, Thor (modified)	Some Hundred Thousand	Hundreds	Tens	-	-	Tens
3	Atlas, Titan (modified)	Several Hundred Thousands	Several Thousands	A few Thousands	Some Thousand (no return)	Hundreds (no return)	A few Thousands (no capture)
4	Growth versions (First (winged) and second stage Lox-Jf; high-energy third stage)	1,500,000	40,000	8,000	6,000 (no return)	4,000 (no return)	7,000 (no capture) 3,000 (capture)
		3,000,000	90,000	20,000	16,000 (with return)	9,000 (no return)	16,000 (no capture) 7,000 (capture)
5	Chemo-Nuclear (Winged first stage)	3,000,000 (Lox-Jf) 230,000 (Nuclear; H_2; I_{sp} = 800 sec)	~160,000			22,000 (no return) 7,000 (return)	30,000 (capture)

* All payload weights for launching from the Earth's surface. In case of return, an Earth satellite orbit is entered.

distant galaxy, the consistency of the lunar surface, and bugs on other planets? Or will we let them degenerate into glorified laboratory technicians concerned with striped tooth paste, next year's automobile, cigarette filters, and new cosmetics? The decision is up to our citizens who in the last analysis determine the size and principal allocation of public funds. Obviously, not all, or even an overwhelming fraction of these funds, can be or should be made available for astronautics alone. But those who even now warn us that we cannot afford the luxury of large-scale astronautic endeavors forget that for about 3¢ per day or $10 per year from each of the approximately hundred million money earning citizens of this nation our space missions, except for major military endeavors, can be financed indefinitely.

Sociological Aspects

The decision is therefore a matter of spirit and slight sacrifice for the future of our children. If the question is put bluntly to the citizens of this nation, I know their response will be overwhelmingly positive. The dire analyses of some of our sociologists notwithstanding, their instinct is healthier and their intuition keener than that of the Plebeians of the late Roman empire who yelled for "bread and games," and they are not urbanized to the extent that they would become unable to care for pioneering into space, being concerned only with their community and the election of that representative who most diligently caters to their particular needs. If the danger of such a development really should exist, then I am sure that the most compelling reason for undertaking space flight is a sociological one—to prevent the human mind from "digging in."

The sociological structure and the collective taste of this nation will in the future, more than ever in the past, be affected and kept in a dynamic state by relentless communist competition which, if it does not degenerate into a hot war, will be waged primarily on the economic, technical, and scientific front. To say that space is by no means the only battle ground is a trivial observation. But it is equally true that it is an important battle ground. We have in the past devoted too little attention to the philosophy of our mission in space.

Solution: The Decision

In the wake of the Sputniks, a multitude of projects and suggestions has been thrown at military and civilian authorities which is confusing to many. However, variety is confusing only in absence of an overall purpose, of a coordinating concept. Determination of the goal requires a few basic policy decisions directed toward reaching a major next platform rather than petty improvements, and these decisions should be backed up by a consistent long-range funding plan. Then we must work toward these goals determined to attain practical accomplishments without allowing ourselves to be lured into an erratic course of stop-gap measures on the one hand and overconservatism on the other.

Space Missions

If we may assume that adequate space capability is a necessity, that it will not drive us into bankruptcy, and will not unduly distract from other important national requirements, we may define the following phases:

(1) Gradual development of orbital capabilities beginning with improved instrumented satellites and continued with inhabitable space stations which are small enough to be maintained by chemical multistage rocket vehicles; aiming eventually at the establishment of a comparatively economic and safe transportation system between surface and satellites thereby opening broader aspects of satellite technology to commercial, medical, industrial, and recreational purposes, if corresponding utilities can be developed.

(2) Gradual development of a lunar capability beginning with instrumented probes and continuing with manned flights into a temporary satellite around the moon with subsequent return to the Earth. These two missions can be flown with chemical multistage vehicles from the surface of the Earth without assembly and fueling in an orbit. The landing of a party on the moon with chemical vehicles requires orbital assembly and fueling. If the establishment of one or more permanent lunar bases is found desirable as a result of the previous activities, the eventual goal must be supply capability of these bases from the Earth's surface as well as the capability of fast passenger flights between Earth and the moon. This requires nuclear propulsion.

(3) Interplanetary and planetary research with artificial comets. Nuclear lunar capability gives us the option of conducting fast manned reconnaissance flights to the planets of the inner solar system, reducing mission periods to about 1 year or less. Comet flights can again be accomplished by means of chemical multistage vehicles while the second step requires nuclear propulsion. Fast inner solar system flights are certainly of great psychological value to the crew which thereby spends years less in space than when following minimum energy routes. It adds to safety because the failure probably is reduced and it affords greater

protection against cosmic primaries, inasmuch as reduction of exposure times seems to be the only effective protection.

Vehicles

Aside from the Jupiter C and the Vanguard vehicles, the American missile arsenal offers IRBM's and ICBM's for a more consequential orbital capability and a first lunar and interplanetary instrument-carrying capability. Table 1 presents a survey of the order of magnitude of payload weights for various missions of five classes of vehicles. It is interesting to note that of these, we already have three classes up to the flight test stage. Of particular interest, is the fifth step which relies on the fourth for a chemical booster, pushing a nuclear stage out of the denser atmospheres. This stage can be used to carry people nonstop to the moon's surface, and, by launching a small fleet of these vehicles, a round trip to Mars or Venus can be carried out from the Earth's surface. A vehicle of this type which can be expected at the end of the next decade truly opens space to man and provides this country with an adequate space capability, as far as payload capacity and space range is concerned for some time to come.

Conclusion

The motto which I have put at the beginning of this paper is a very important one in general and very relevant to astronautics in particular. In the course of the relentless pressure for new knowledge and greater technical achievements which characterizes our era, we have come face to face with a vast challenge and with the serious problem of how to meet this challenge properly. There is no doubt that we are capable of meeting it. But halfhearted measures are not the answer. When we made the transition from automobile to airplane we had to make a significant jump in velocity of motion. It was safer to be bold and make this jump than to try to develop airplanes gradually to higher speed, beginning with 35 m.p.h. I would like to add to the motto that, as things are in this world, the most expensive and dangerous way of undertaking a vast project is with half vast ideas. We must therefore be careful not to confuse half vast ideas with balanced thinking. This does not mean to advocate an hysterical all-out concentration on space flight in this nation. It means that we cannot meet this challenge without setting ourselves a few intelligent advanced goals which bring within our practical reach a multitude of other capabilities to be utilized at our discretion as pointed out above. It is not the advanced goal but the lack of one and the accompanying erratic and inconsistent activity which make such developments expensive.

The philosophy of our mission in space must be one of leadership and cooperation with other nations, of contributing to the storehouse of human knowledge, and of opening new worlds and new freedoms to man while we make very sure that the old freedoms left on this beautiful planet do not get lost in the shuffle which we call the opening of the space age.

✦ ✦ ✦

Hypersonic Aerodynamic Factors (Continued from page 33)

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The proposed and in-use radio navigation systems for long-range flight are described with mention of their operating characteristics and suitability for modern high-speed air operations.

Radio Navaids for Long-Range Flight

Mortimer Rogoff

Federal Telecommunication Laboratories
A Division of International Telephone and Telegraph Corporation

THE PURPOSE of this paper is to establish clear lines of division between various radio navigation systems and, by defining the various classes, to describe the basic characteristics of each type of system. It is hoped that the result of such definition and description will allow the reader to assess the suitability of a radio navigational system to his own particular needs.

Classification of Long-Range Radio Navigation Systems

The essential characteristics which define any ground-based long-range radio navigation system are:

(1) The number of transmitting antennas associated with a single line of position.

(2) The relative spacing of antennas used to form a line of position.

(3) The choice of operating frequency.

By making a choice within each of the three characteristics listed above, a particular system is specified.

The number and spacing of transmitting antennas associated with the ground stations is perhaps the most definitive of the characteristics of a radio navigation system. It is from the variations of these antenna arrangements that the basic system lines emerge. Let us consider these in detail.

The simplest configuration is a single vertical omnidirectional antenna tower. If a steady unmodulated radio frequency carrier is radiated from this tower, it is possible to measure distance travelled with respect to this tower by means of a phase comparison process. The result of such a measurement is to place the observer on a circular line of position with respect to the tower. To do this, it is necessary that the observer carry with him a signal source whose frequency is identical to that of the transmitted carrier and which is in phase with the source at the transmitter station.

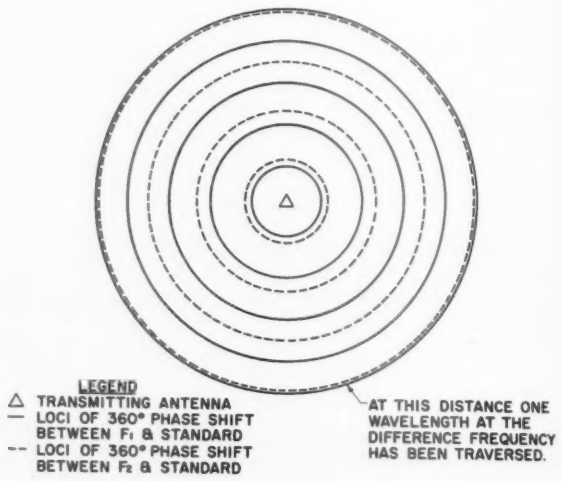
LEGEND
△ TRANSMITTING ANTENNA
— LOCI OF 360° PHASE SHIFT BETWEEN F1 & STANDARD
-- LOCI OF 360° PHASE SHIFT BETWEEN F2 & STANDARD
AT THIS DISTANCE ONE WAVELENGTH AT THE DIFFERENCE FREQUENCY HAS BEEN TRAVERSED.

FIG. 1.

Referring to Fig. 1, circular lines about the transmitting antenna are drawn which represent contours of constant range from the station. The wave radiated outwards from this single antenna undergoes phase delay linearly with respect to distance travelled; 2π radians of phase delay are encountered for each wavelength of the signal frequency traversed. Thus, if the carrier frequency is 100 kc., 2π radians or 360° of phase delay is encountered every 1.617 nautical miles. If the phase of the received carrier frequency is measured with respect to the reference oscillator (which is a replica of the transmitter's frequency and phase) by the observer, this phase change of 360° for each 1.617 nautical miles will be displayed as the distance changes radially from the station.

A system as simple as this one does exist; it is the distance measuring portion of Navarho. There is one difficulty associated with this simple type of one-way distance measurement, namely, the fact that an ambiguity exists for each wavelength traversed. The

Mr. Rogoff is an Executive Engineer.

phase angle measured between received signal and reference signal will be the same within each whole wavelength interval. Either the receiving equipment must measure elapsed distance continuously (in which case there will be no ambiguity), or the requirement exists for some form of dead reckoning or other guidance in order to establish which wavelength interval is being measured.

To overcome this difficulty, the radio system can employ the simultaneous transmission of more than one frequency from this single transmitting antenna. If more than one frequency is transmitted, the second set of contours shown in Fig. 1 is employed to resolve the distance ambiguity. The second frequency necessarily possesses a slightly different wavelength than the first. If phase is measured separately at each frequency (against two separate reference sources at the receiver), it is observed that at any given distance from the transmitter the two phase angles measured will be different. This occurs because of the difference in wavelengths traversed at these two different frequencies. These two simultaneously measured phase angles determine a single distance from the transmitter. These sets of readings remain unambiguous until sufficient distance has been travelled for the two measured phase angles to differ by 360°. Beyond this point the cycle repeats, and a second zone exists where ambiguities may be resolved.

The simultaneous transmission of two frequencies constitutes a form of modulation on a basic carrier. This is exactly analogous to a double side band suppressed carrier system of transmission. For example, if 100.05 kc. and 99.95 kc. are the radiated signal frequencies, then signals received in the airplane would have all of the characteristics of a double sideband suppressed carrier signal of 100 kc. carrier frequency, with 50 cps modulation. This is the exact form of the distance measurement signal transmitted in Navarho, and, by the methods described above, measurement is made on the carrier alone to obtain a "fine" distance measure which traverses through 360° every 1.617 nautical miles. A "coarse" measurement made at the 100 cps difference frequency produces one phase rotation every 1617.0 nautical miles.

The next general form of system is any one employing more than one transmitting antenna. In Fig. 2, two such antennas are shown, and two circular lines of position which denote the contours of a constant phase angle measured with respect to each station are plotted. These two circles are tangent to each other at a point along the baseline joining the two stations. At this point, the measured phase angle difference is the difference between the two phase angles that would be measured separately with respect to each station. As one moves off the baseline, this constant difference will be observed on a hyperbolic contour falling between the two circular lines. Some artifice such as a difference in transmitted frequency or a form of time sharing must be employed to separate these two received signals for the purpose of measuring.

Assuming that this is done, the contours of constant phase angle difference measured between these two signals will take the form of hyperbolas constructed between these two stations. Any hyperbolic line drawn through the baseline represents the locus of points of constant differential distance, hence constant differential phase delay measured between the two stations.

One important advantage of these two antenna systems is the fact that the observer need not carry with him a reference frequency generator for use in measuring the phase of the received signal. These two signals are separately received (either in frequency or by virtue of time separation), and one can be employed as the phase comparison standard for the other since only differential quantities are being measured.

A whole class of systems evolves from this differential, or hyperbolic, technique. Among these are Loran A, Loran C, Dectra, and Omega. The variations between these systems involves the methods for separating the two signals, the methods with which the measurements are made, the form of modulation employed, and the baseline separation between the antennas.

The simplest concept of a hyperbolic system is that embodied by standard Loran A. In this case the transmitters at each station will be pulsed on for brief periods of time rather than running continuously. An observer at a position midway along the baseline will receive these pulses simultaneously. As the observer changes his position relative to these two stations along the baseline, he will measure a changing differential delay pattern due to his motion. Along this line, the phase change measured in delay will occur at the rate of approximately 12 μ's per mile travelled. Off the baseline, the constant delay contours are hyperbolic and the actual measured differential delay will depend upon the observer's position on this hyperbolic grid.

As far as the actual measurement of phase or time delay is concerned, the transmitted pulses are extracted from the signal without regard to the carrier frequency

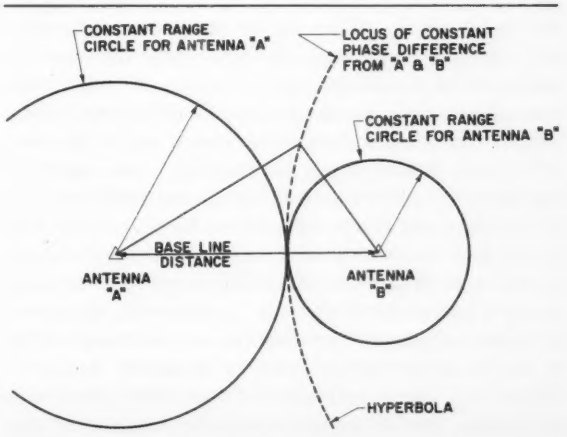
CONSTANT RANGE CIRCLE FOR ANTENNA "A"
LOCUS OF CONSTANT PHASE DIFFERENCE FROM "A" & "B"
CONSTANT RANGE CIRCLE FOR ANTENNA "B"
BASE LINE DISTANCE
ANTENNA "A"
ANTENNA "B"
HYPERBOLA

FIG. 2.

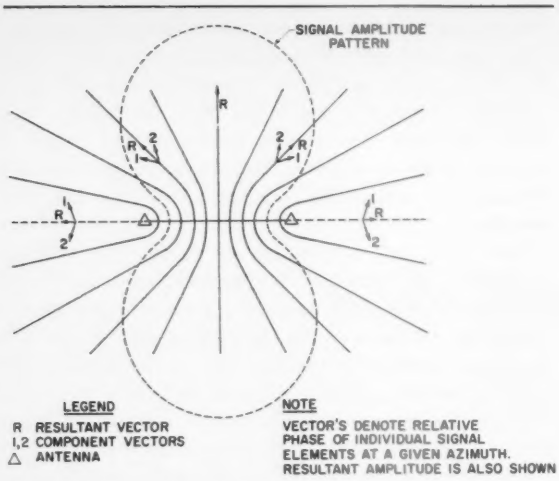

FIG. 3. Narrow baseline differential distance system used to generate azimuthal coordinates.

employed. These measurements are made on the envelope of the received signal (which in this case constitutes a form of modulation), and no measurements are made at carrier frequency. In other words, there is no fine and coarse measurement made in standard Loran A since the phase delays of the carrier frequency (which change rapidly with differential distances) are ignored.

The important variation on Loran A is Loran C. Loran C employs measurements made on the carrier as well as measurements made on the received pulse envelope. In this case, the fact that the transmitters are pulsed on the air and received at different times allows a differential phase measurement to be made in the receiver even though both transmitters use the same carrier frequency. The fact that signals will never be received simultaneously is guaranteed by the fixed delay that exists between transmission times at these two stations. This delay is inserted in the synchronizing system that joins the two stations for timing purposes.

The phase of the received pulse of carrier is "stored" in the receiver by measuring the phase angle of the first pulse of carrier with respect to a locally generated reference signal. When the second pulse of carrier is received, the phase angle between it and the receiver's reference is measured; the difference between these two phase angles is the quantity of differential carrier phase. Since these two pulses arrive within fractions of seconds of each other, the stability requirements on the receiver's reference oscillator are relatively low.

As in the case of all carrier phase measurements, lines of position obtained from this fine portion of the Loran C system are ambiguous since they recur approximately every 0.8 nautical mile. The ambiguity is eliminated by means of delay measurements made on the envelope of the received carrier pulses in a manner similar to Loran A. These measurements establish which fine hyperbolic line of position is being tracked by the carrier phase portion of the system.

Still another variation of hyperbolic systems is that typified by the Omega system. In this case the transmitters in the system radiate their signals one at a time on the same frequency. Individual signal durations are 1 or more sec. This, of course, is simply a very long pulse of carrier; the receiver accepts these signals one at a time and measures their phase relative to an internal standard. A phase angle difference that is measured between signals places the observer on hyperbolic lines of position that characterize pairs of stations. Since these measurements are made at carrier frequency (at approximately 10 kc.), ambiguities exist approximately every 8 nautical miles. These ambiguities are resolved by further transmissions at an offset carrier frequency. The offset amounts to approximately 500 cps. Hence, as described earlier, this is equivalent to making measurements on a 500-cps basis with a corresponding spacing of approximately 160 nautical miles between ambiguous zones. Therefore, Omega also consists of both fine and coarse measurements; the first made on the higher frequency carrier basis and the latter performed at the 500-cps frequency difference.

The Dectra system is also a hyperbolic system wherein the signals used for phase difference are also transmitted one after the other at the same frequency for one set of hyperbolic lines and at two different frequencies for an orthogonal set of position lines. All measurements are made at "carrier" frequency in Dectra, with ambiguous zones recurring approximately every nautical mile on the baselines. Because of the spreading of the hyperbola away from the baseline, the zones of ambiguity widen to as much as 30 nautical miles at the range extremes of the system.

There is another important variation of hyperbolic systems that is created when very narrow spacing is used between transmitting antennas. In this case, the spacing of the antennas is generally much less than a wavelength at the carrier frequency employed. Fig. 3 is illustrative of this type of system. When the spacing between antennas is, for example, 1/3 of a wavelength, or 120 electrical degrees, it is clear that the maximum phase difference that can be measured between signals received from these two antennas is never more than 120°. This amount of differential phase shift would be obtained on the extension of the baseline drawn between the two antennas. As the observer moves around the station, this differential shift of 120° will reduce to 0° when he is on the perpendicular bisector of the baseline and will then increase as he approaches the other baseline extension. If, instead of measuring differential phase, the derived quantity of received signal amplitude is used for measurement, it is possible for the observer to position himself with respect to the amplitude pattern thus formed. When transmissions are made simultaneously at the same frequency (by means of a common transmitter) from these two antennas, it is seen that the vector addition of the two signal components (one from each antenna) that coexist at the observer's location produce this amplitude variation in the resultant signal strength.

The use of amplitude measurement is especially convenient when it is desirable to transmit simultaneously on only one frequency and when no reference signal is to be carried in the airplane. The amplitude pattern that exists around such a pair of stations is shown in Fig. 3 as a "dumbbell" variation as azimuth changes with respect to the station. This is the basis for the bearing measured portion of the Navarho system. By using three transmitting antennas energized in pairs one after the other in time, three such amplitude patterns will be produced. Each antenna is located at a corner of an equilateral triangle, hence the patterns are shifted 120° relative to each other. These three superimposed patterns are shown in Fig. 4. An observer located at a particular bearing angle with respect to the station will receive three different amplitudes of signal one after the other during the sequence of transmission. The simultaneous existence of these three amplitudes designates the bearing with respect to the station. The translation of the sets of amplitudes into bearing angle results in radial lines of position. This is in contrast to the hyperbolic lines of position that exist between a pair of widely spaced antennas.

We have shown that variations between the number and spacings of transmitting antennas result in a variety of systems. A single antenna produces contours of phase difference which form circular lines of position around the station. Pairs of antennas produce hyperbolic LOP's between the baseline of the pair. Measurements made at carrier frequency result in LOP's which recur every few nautical miles; measurements made at two carrier frequencies produce LOP's that repeat at the wavelength of the difference frequency. Hence, this "modulation" measurement is able to resolve the position ambiguities inherent in the carrier measurements.

Finally, when transmitting antenna pairs are spaced by extremely short distances (less than a wavelength at the carrier frequency), the differential phase characteristic can be transformed into a simple amplitude pattern. Calibration of a suitable array of this type results in radial lines of position.

Thus, variation of antenna arrangements produces either circular, hyperbolic, or radial lines of position. Within these variations lie Navarho, Loran C, Omega, and Delrac.

There are many other considerations which become important when one wishes to assess the desirability or utility of a particular system to the needs of his own service. All of the systems mentioned above employ great electronic skill to maximize the accuracy of computation and measurement on the signals received in the aircraft. Similarly, great effort is expended to control the accuracy and stability of the radiation from the transmitters. The one factor which is difficult for the system designer to control is the behavior of the radio signals as they traverse the medium of propagation on their way to the receiver. This problem of propagation distortion is of great importance in choosing and assessing a particular system. Because of its importance we will discuss some of the essential characteristics of radio propagation at the frequencies usually employed in low-frequency radio navigation systems.

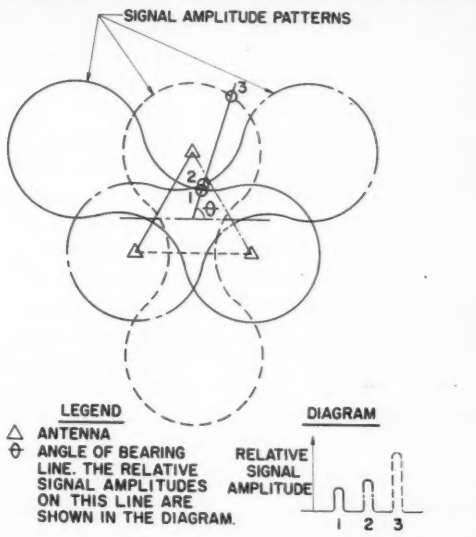

FIG. 4. Signal amplitude patterns for three narrow baseline stations.

All of the systems proposed for serious consideration as long-range radio Navaids operate at or below 100 kc. The principal reason for this choice of frequency is the ability of signals in this frequency range to propagate over the required long distances with little diurnal or seasonal variation. Also, this is a region of relatively low atmospheric noise so that signal-to-noise ratios at distant points are higher and more reliable than they would be at high frequencies. Finally, there are no "skip zones" that are typical in the high-frequency region from 3 to 30 mc. These skip zones are intermediate regions of absence of signal; there would be no navigation coverage in such zones.

The actual choice of an operating frequency anywhere between 10 and 100 kc. depends upon the needs and purposes of the particular system.

The Loran C system employs short pulse transmissions and must operate in the vicinity of 100 kc. One hundred kc. represents a frequency below which it is usually not possible to transmit short pulses. This arises from the fact that all transmitting antennas operating at these frequencies are electrically short. An antenna 650 ft. in height is approximately 1/15 of a wavelength high at 100 kc. As a result, these antennas do not look like pure resistance to the transmitter but possess large amounts of capacitative reactance and a very small amount of either radiation or ground loss resistance. In order to operate the transmitters into these antennas, the capacitative reactance is resonated by means of large low-loss inductors resulting in a series resonant circuit of extremely narrow bandwidth. The consequence of this narrow bandwidth is that it is very difficult to transmit short pulses, and, at fre-

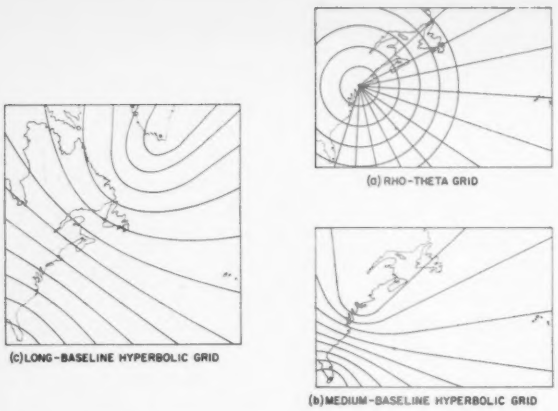

FIG. 5. Relative appearance of lines of position as antenna spacing varies.

quencies below 100 kc., pulse transmissions are usually not attempted. Thus Loran C, for example, is a system that one does not operate below 100 kc. in order to use the short pulses that are required for its accuracies.

The use of short pulses in the Loran C system represents a serious attempt to overcome the difficulties associated with sky wave transmission by means of ionospheric reflection. It is well known that there is a ground wave mode of propagation which does not employ sky wave reflection as a means of propagating a radio signal. In every case, the first component of a signal received at a distant point is due to the arrival of a ground wave; it is received first because it has travelled a shorter path than the sky wave. If a steeply rising pulse is transmitted, there is approximately 30 μ's of time at the receiver during which the ground wave can be perceived without contamination from the sky wave. During this 30 μ's, measurements can be made on the ground wave carrier phase resulting in accurate lines of position. Unfortunately, the price that the designer pays for the use of ground wave propagation is the fact that this signal becomes severely attenuated and undetectable beyond approximately 1,000 nautical miles from the transmitter. At shorter distances, Loran C provides superior accuracy since its measurements are made on a ground wave carrier phase basis.

The bearing measuring system associated with Navarho cannot operate much below 100 kc. This system employs three transmitting antennas spaced 1/3 wavelength apart at the corners of an equilateral triangle. As the frequency is lowered, the wavelength increases; hence the required antenna spacing grows larger. It becomes impractical to own or control the land area that would be required for 1/3 wavelength spacing at very low frequency. The spacings of Navarho antennas at 100 kc. are 1,000 meters or 3,280 ft.: this is about as far as one wishes to go in station size. Hence, there is a real low-frequency limit imposed upon the construction of such a station.

The Navarho System which operates at 100 kc. possesses a set of advantages which make it particularly suitable for aircraft operation. Navarho provides its data in the form of bearing and distance to a transmitter station. The straightforward one-way measurement of distance from a single transmitting antenna, employing the simultaneous transmission of two frequencies, provides circular lines of position which measure distance from the station. The narrow baseline separation between the triple transmitting antennas provides radial lines of position (always perpendicular to the circular distance contours). Moreover, a single Navarho ground station provides a position fix, not just a line of position obtained from two stations working as a hyperbolic pair. The set of ρ, θ coordinates—distance to the station and direction to the station—provides natural guidance to a pilot or navigator without recourse to any additional computer. All rho-theta systems, such as Navarho, provide increased accuracy of fixes as the aircraft approaches the stations. In most situations, the accuracy requirements in the middle of a long-range flight are not as severe as the need for position fixing upon entry to the more crowded areas of the destination. Hence, Navarho is much like a beacon system which provides tighter and tighter guidance as the airplane approaches the terminal area of a congested region.

The choice of operating frequency in the Dectra system is governed by the desired spacing between hyperbolic lines of position. These frequencies are chosen so that in the central areas of coverage 360° of differential phase (at the carrier frequency) will occur approximately every 2 miles. This figure is determined exclusively by the choice of frequency and the present Dectra system operates at approximately 70 kc. based on such a consideration.

The transmitting stations that are used to form the Dectra "tracks" are spaced a few hundred miles apart. The hyperbolic lines of position which radiate outwardly from the central section of the baseline between the stations are almost parallel, hence they lend themselves to simple instrumentation for flight guidance. These tracks or lanes are approximately 5 miles apart. By providing a pair of stations on one shore line and a second pair on the opposite shore of an ocean area, essentially continuous tracks can be provided for over-ocean flight within this central region of the two baselines employed. The advantages of carrier phase measurement, with its large sensitivity to small changes in differential distances travelled, is retained in Dectra. The limitation of Dectra is the fact that these almost parallel tracks do not exist when the observer is removed from the central baseline section. Dectra provides accurate coverage over long linear areas and lesser or no coverage on the "sides" of the system. Since no computer is used, the information is displayed on recorders that trace motions on hyperbolic coordinates. These motions are not easily transformed into steering guidance for navigation.

The Omega system, which operates in the vicinity of 10 kc., provides superior accuracy and stability and an extremely long range of service from a single pair of

stations. The long range is available since sky wave transmission at these low frequencies is so efficient and stable that it is possible to predict contours of phase delay even though the signals have traversed many thousands of miles and multiple reflections have taken place at the ionosphere and at the surface of the earth. In addition, since the Omega stations can be placed thousands of miles apart, the hyperbolic lines of position show relatively little curvature with respect to a set of parallels drawn between the baselines. Hence, even though these lines are hyperbolic, their relatively small curvature and spreading allows easy charting, instrumentation, and display of the data.

The various types of navigating grids formed by changing antenna tower spacing are illustrated in Fig. 5. Fig. 5(a) shows the intersecting distance and bearing (rho-theta) lines of position which are created from a single station site employing narrow baselines. Bearing is measured in the receiver by means of the resulting amplitude pattern, and distance is measured by phase comparison between the received signal and a frequency standard carried in the airplane. This is typified by the Navarho System.

Fig. 5(b) illustrates the lines of position that are obtained from a pair of transmitting antennas spaced many hundreds of miles apart. Such systems as Loran A and Dectra provide this type of navigational data. Fixes are obtained in these systems by means of a second set of intersecting hyperbola derived from at least one additional transmitting station or from a second pair. The Dectra system employs only those lines of position in the central section of the region of coverage. These lines are essentially parallel, and they provide track guidance with a minimum of distortion.

Fig. 5(c) is illustrative of hyperbolic lines of position obtained by widely spaced antenna towers. In this case, the antenna towers are spaced by approximately 4,000 miles. As a result, an extremely large area on the surface of the earth is covered by these lines of position, and, in most of this area, the lines are essentially parallel to each other. In order to obtain a fix, intersecting hyperbolas are used.

Throughout this discussion no attempt has been made to describe the equipment, either ground or air, which produces the signals or computes and displays the data. Such equipment descriptions are readily available from many sources and have been described in great detail in literature on the subject. In order to portray the state of the art in terms of equipment, a tabular summary of present system apparatus is contained in Table 1. In this table, it is possible to see at a glance the comparative performance and equipment sizes and weights that currently apply to these systems.

No discussion has been included relative to the self-contained Doppler type of radio Navaid since they represent a completely different class of electronic navigation systems. They are sensors of motion; they are in effect an addition to the normal flight instruments of the aircraft. When they are coupled to appropriate heading references these self-contained systems can provide useful navigational data. In all likelihood ground-based radio navigation aids will always be required to correct the inherent errors of these self-contained sensors. Since radio Doppler, or inertial navigation systems apply equally well to both short-

(*Continued on page 54*)

TABLE 1
System Characteristics

System & Type	Frequencies	Base Line	Origin	Approx.* Weight	Range	Accuracy	Transmitter Power Output
Navarho† Distance & bearing (ρ, θ)	90–100 kc.	3,700 ft.	...	90 lbs.	2,600 nm (over sea) 2,000 nm (over land)	±10 nm Tapering to ±1 nm	15 kw.
Loran C† Hyperbolic	90–110 kc.	600 nm (approx.)	Loran	...	1,200 nm, land (within grnd. wave region) Accuracy diminishes when sky wave employed	1/6 nm	100 kw. (peak power)
Loran A† Hyperbolic	1.75–1.95 mc.	200 nm (approx.)	...	50 lbs.	600–800 nm, day 400–600 nm, night 600–1,000 nm, night	1/4 nm 1/4 nm 1–2 nm	150–1,000 kw. (peak power)
Consol† Bearing (aural measurements)	250–400 kc.	Order of 1 wavelength	Sonne	Uses ADF Rcvr.	1,500 nm, sea	1/4° to 1°	10 kw.
Omega Hyperbolic	10–14 kc.	5,000–6,000 nm	Radux	...	6,000 nm	1–3 nm	...
Dectra† Hyperbolic	70 kc.	80 nm, tracking 2,000 nm, ranging	Decca	140 lbs.	2,000 nm	Tracking ±5 nm Ranging ±10 nm	12–21 kw.
Delrac Hyperbolic	12 kc.	3,000 nm	Decca	...	3,000 nm	10 nm	...

* Airborne equipment only.
† Systems that have been in use or demonstrated.

XUM

J. C. Fletcher
The Ramo-Wooldridge Corporation

Guidance and Control Problems in the Air Force Ballistic Missile Program, Part I

EDITOR'S NOTE: *Because of the author's comprehensive and timely report of a task of vital importance to the nation,* AERO/SPACE ENGINEERING *is publishing this article in two issues. Part I discusses guidance analysis, control system problems, and radio guidance problems. Part II, to be published next month, will cover inertial guidance problems, equipment design, and future trends.*

WHEN THE Air Force initiated the accelerated development of an ICBM missile, a problem of unprecedented magnitude was presented. It was necessary to assemble, in the shortest possible time, a team of scientists, engineers, and industrial concerns which not only could ensure rapid development of an operational missile but also could phase the development rapidly into production adequate to furnish this nation with an ICBM operational capacity at the earliest possible date. After preliminary design work and feasibility studies by The Ramo-Wooldridge Corporation,* contracts were placed with a large number of industrial concerns, each having particular experience in both the development and the production of some portion of the missile hardware.

At the outset, both technical and management problems looked very formidable indeed. After thorough consideration of all aspects, Ramo-Wooldridge was selected to assist in these closely related areas. Of immediate concern was the fact that many of the problems of re-entry, guidance, propulsion, etc., required extensions of the engineering art. Of equal concern was the knowledge that the various industrial contractors in most cases had never before worked together on a weapon system of such scope, and, in no case, to be sure, had they been required to cooperate to the degree required for such an expedited, widespread program.

* Now the Space Technology Laboratories of The Ramo-Wooldridge Corporation. STL now has the responsibility of technical management and system engineering of all four Air Force ballistic missiles programs—Thor, Titan, Atlas, and Minuteman.

Dr. Fletcher is Director of the Electronics Laboratory at the Space Technology Laboratories.

Now that we look back on what has proved to be a successful subsystem development program and are well into the flight-test program, the problems perhaps do not seem so great. However, it has become apparent that, because of the great effort initiated by this program, there has been much advancement of the state of the art of all fields related to the ballistic missile program. Many technical problems have been solved, many new components have been developed, and numerous techniques have been invented and utilized which will be useful on future programs. Not the least of these advances have been in the field of electronics. The intent of the material to follow is to discuss the principal problems that have been encountered in the guidance and control area and to indicate, where security restrictions permit, some possible solutions to these problems.

GUIDANCE ANALYSIS

The function of the guidance and control system for a ballistic missile is to establish an appropriate flight path during the boost phase of the trajectory and to terminate thrust at an appropriate velocity and position in space so that the resultant ballistic trajectory intersects the earth at the target point.

A generalized block diagram of such a system (Fig. 1) includes:

(1) *The measurement system.* This system must accurately measure, as a function of time, the velocity and position of the missile in a coordinate system which can be accurately tied to the target coordinate system. This measurement system must transmit this information through a data channel to the computer.

(2) *The computer.* This device must reduce the in-

formation from the measuring device to the proper form and coordinate system, then estimate which corrections must be made to the missile flight path in order to properly establish the missile on a collision course with the target, and finally, at the appropriate time, generate a thrust termination signal. The computer must transmit this information over a second data channel in the form of missile steering commands and engine shutoff commands.

(3) *Control system.* The control system, or autopilot, receives the commands from the computer and either manipulates control surfaces or jet vanes or gives engine swiveling commands, which will force the missile into the proper heading. The control system, as defined in Fig. 1, includes the shutoff device for the engines. The control system then perturbs the trajectory; this perturbation is in turn detected by the measurement system, thereby closing the guidance system loop.

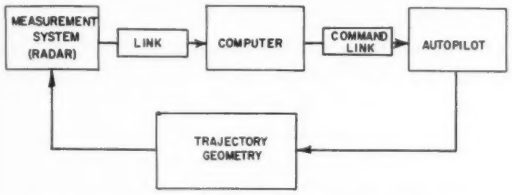

FIG. 1. Generalized block diagram for guidance loop.

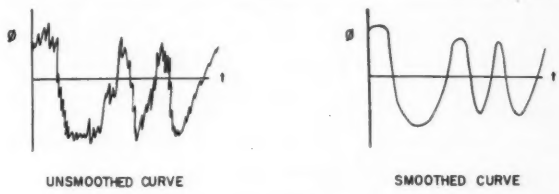

FIG. 2. Effect of smoothing on tracking signal.

The measurement system, to a large extent, determines the overall accuracy of the guidance system. Its basic problem then is to measure accurately position ($\vec{x}$) and velocity ($\vec{v}$) in the vicinity of burnout of the engine. The accuracy with which $\vec{x}$ and $\vec{v}$ must be measured, of course, depends critically on the shape of the trajectory and on the range to the target. It can easily be seen that, for reasonable miss distances at the ranges specified for IRBM and ICBM, great precision from the measurement system is required. Two systems commonly used for this purpose are (1) the radio system and (2) the inertial system. In the *radio system* phase difference between the transmitted and the received energy between missile and ground is used as a measure of the distance between ground radar and missile. Two transmitters or receivers on the ground, at some distance from each other, can be used to determine one angle (by measuring phase difference between the received signals at the two stations). The simplest example of this type of system is a tracking radar which obtains range by measurement of the time difference between transmitted and received pulses and which obtains angle by measuring the phase difference between two adjacent feeds located at the focus of a parabolic antenna. Measurement of the range and the two angles is sufficient to give $\vec{x}$; $\vec{v}$ may be obtained either by differentiating $\vec{x}$ or by measuring phase-rate differences directly.

The *inertial system* makes all trajectory measurements on board the missile by means of accelerometers. If the three components of acceleration in inertial space are measured by accelerometers, one can integrate once each to obtain $\vec{v}$ and twice each for $\vec{x}$. Since acceleration must be measured in inertial space, the accelerometers used must be mounted on a platform stabilized by appropriate gyroscopes to maintain the components of acceleration in a fixed coordinate system. Accelerometers actually measure inertial acceleration plus the force of gravity. The local gravity vector must be precomputed for powered flight and subtracted from the measured value of acceleration. The target, of course, is not motionless in inertial space; therefore appropriate corrections must be made for the target's motion. Both inertial and radio systems have one feature in common—they both depend critically on the initial alignment of their respective coordinate systems with the coordinate system in which the target is known. This requires an accurate survey of the area in the neighborhood of a launch site, as well as accurate initial alignment of the equipment with these surveyed points.

Aside from the alignment problem, all radars have one characteristic type of error. The spurious phase fluctuations, due either to propagation or to equipment errors, are often such that accurate phase rate ($\vec{v}$) information is obtainable only when the signals are smoothed over an appreciable length of time. This is particularly true in the case for which phase rate is not measured directly as in a Doppler system but is obtained by time-differentiating phase differences.

In general, the longer the period over which the fluctuations are smoothed, the more accurate the estimate of velocity, provided that the actual or real velocity fluctuations either are extremely small or are fluctuating slowly. It can be seen from Fig. 2 that the slopes (velocity) in the smoothed case are greatly reduced. Here we come to one of the basic compromises in the radio system—smooth long enough so that the fluctuations in the measurement system are averaged out to a small value but not so long that uncertainties in the value of the missile acceleration will give rise to appreciable velocity errors* during the smoothing intervals.

The chief characteristic of the inertial guidance system is that the longer the period of time during which the measurement is made, the longer the period over which the acceleration must be integrated, and con-

* This velocity error is approximately equal to the acceleration uncertainty times the smoothing time.

sequently the larger the possible velocity error. This assumes that the nature of the acceleration error remains constant during the integration time. The basic problems with an all-inertial guidance system are (1) to obtain platforms which exhibit very low angular drift during the guidance period and (2) to mount on the platform accelerometers which exhibit errors of such small fractions of 1g that when these errors are integrated over the guided flight period they will give rise to small velocity errors.

An extremely interesting system is one which combines the best features of the radio with those of the inertial, the so-called "radio-inertial" system. In this system the smoothing time over which the radar data can be averaged can be made very long by using the inertial elements to measure the actual acceleration during the smoothing time. Stated another way, the radar is used to correct the inertial guidance errors at intervals of one smoothing period apart. The same optimization of smoothing time constant as used above can then be applied, but in this case the uncertainty in acceleration *measurement* is used, not the uncertainty in *actual* acceleration. This system, then, clearly gives greater accuracy than either the radio or the inertial system by themselves, provided one can measure acceleration more accurately than the unknown fluctuations in the acceleration itself. The only problem with such a system is that, although it combines the accuracy features of both radio and inertial systems, it unfortunately contains the added unreliabilities and added weights of both systems. Here is a situation where we may, if we choose, gain accuracy at the expense of complexity and weight.

The general problem of what type of computer to use is a difficult one. The computer used, of course, depends critically on the guidance equations (see feedback loop in Fig. 1) and on the trajectory to be followed. It is, in general, wise, in order to simplify the computer design, to make the maximum use of the nominal flight path that the missile would follow without guidance signals. One then computes small deviation from this, using linear approximations, where possible, in the error expansion. In general, these deviations become smaller as uncertainties in thrust and the autopilot fluctuations become smaller. The question of analog versus digital computer naturally arises. A digital computer allows greater flexibility in the guidance equations and has no inherent accuracy limitations. The "flexibility" argument is perhaps important primarily in the early development stages of the program since it is often desirable to change the guidance equations frequently as new information is received from the component and missile test programs. An analog computer, on the other hand, usually has the advantages of simplicity and ease of maintenance and operation. The choice, then, of analog versus digital depends (1) on the accuracy desired, (2) on the development status of the program, and (3) on the particular choice of guidance system used.

It should be emphasized in connection with the guidance analysis problem that the trajectory itself is an important system compromise which must be made. One must weigh considerations of (1) maximum range, (2) minimum guidance errors, (3) minimum skin friction heating, etc.; and also one must (4) allow an adequate means of separating the various stages of the missile, if required, and (5) allow for the appropriate antenna look angles from both the missile and from the ground, if the radio system is used, so that adequate signal strength is received at both antennas. These compromises must all be considered analytically, and precise calculations must be made regarding the cost of each of the possible compromises.

Control System Problems*

The basic problem of the control system is to maintain an extremely large vehicle as closely as possible on a predetermined flight trajectory. In the absence of any atmosphere, the missile is basically unstable. It can be even less stable within the atmosphere, because of weathercock instability, unless appropriate stabilizing surfaces are used as part of the airframe. The difficulty in designing the appropriate servocontrol depends on the disturbances which are anticipated. Disturbances may be (1) guidance induced, (2) internally induced (backlash, friction, dead space, etc.), or (3) externally produced (gusts, winds, tip-off at launching, etc.). One of the important disturbances is upper atmosphere winds. Even though such winds often occur at very high altitudes where air density is low, the missile velocities attained are of such magnitude as to give rise to large dynamic pressures (q) which may cause large turning moments. Extremely tight servocontrol must then be used to keep the missile headed into the relative wind to prevent tumbling.

The control system, therefore, must be a sort of precision servo with very little hunting or drift during the accurate guidance phase. This, coupled with the large size of the missile, gives rise to some special problems. First, it is quickly recognized that the larger the missile, in general, the lower the frequency of the major body bending modes. Since the control system gain must be high to prevent missile tumbling, the crossover frequency of the servosystem may very well compare with the lowest body bending frequency. This may give rise to an instability at the fundamental bending mode, thereby causing breakup of the missile. Careful design of filters and compensating networks is required to avoid this problem.

A second problem is that of fuel sloshing. Because of the large amount of fuel necessary to boost the missile to the required velocity, a rather low sloshing frequency may result. Also, because of the large ratio of fuel weight to structure weight, the coupling of this fuel motion back to airframe motion is rather tight. To complicate the problem further, the fluid damping of

* All control system equipment is supplied by the airframe contractors (Convair, Douglas, and Martin).

such sloshing modes is very small unless special precautions are taken to provide baffles to the fluid motion —as is well known to designers of oil tankers. The problem is not dissimilar to that of trying to balance a pail of water on the end of a broomstick. It can possibly be done, but the problem is certainly made easier by providing appropriate damping within the fluid and also by a preknowledge of the basic sloshing frequency.

A third problem is that of actuator speed. Because of the requirement for a tight servoaction and a rapid force response, one is faced with the problem of very rapidly moving large control surfaces, jet vanes, or actual thrust chambers. Actuator forces of the magnitude required can usually be obtained; the design of a fast actuator servo has the attendant problems of actuator stability, whether it be hydraulic, pneumatic, or electrical.

Radio Guidance Problems*

The principal problem that concerns the radio guidance system is that of constructing the highly precise components used to measure phase difference accurately. Highly stable electrical circuits must be used, as well as precision mechanical components. Their characteristics must not change with time or environmental stress. Inventions can be used which minimize the effects of either electrical or mechanical drifts. These techniques are well known to those involved in the development of precision monopulse tracking radar, such as those used with surface-to-air missile programs. The basic difference between these and the radar required for the ballistic missile application is that all measurements of phase angle range, etc., must be made in absolute or earth coordinates since the target in this instance is fixed in earth coordinates and not in radar coordinates. This requires, as was mentioned above, accurate alignment of the system and an accurate geodetic survey grid.

There are some basic physical problems which are encountered which soon become apparent when ultimate accuracy is required of the radio components. One problem is the scattering of the radio waves during propagation through the various portions of the troposphere. It is well known that the index of refraction of the atmosphere is not that of a vacuum but is generally higher because of the water vapor content. The index of refraction is on the average 1.00034. This index of refraction varies from place to place and from day to day, but the mean index would require an angular correction to any line-of-sight measurements using radar of about 0.93 millirad. measured at an elevation angle of 20°, assuming that the object being tracked was above the main portion of the troposphere. Lower elevation angles, of course, give longer path lengths in the troposphere which result in correspondingly larger angular corrections.

In addition to the shift in mean index of refraction, fluctuations in refractive index due to changes in atmospheric density and in water vapor content are also common. These fluctuations are apparently due to turbulence in the lower atmosphere since the statistical properties of the index fluctuations seem to be identical with those of the turbulence itself. These fluctuations are also believed to be the principal factors which make scatter propagation possible (propagation of electromagnetic waves beyond the line-of-sight due to scattering in the troposphere). This type of propagation disturbance is, of course, impossible to correct for, and therefore it gives rise to errors in velocity and position measurements. The size of these errors will, of course, depend on the weather, on the prevailing wind velocity, on the local terrain, and on the elevation angle to the missile.

Another type of atmospheric condition giving rise to large phase difference fluctuations is the presence of clouds. As one might expect, a sharp change of index of refraction is observed on passing from just inside of cloud to just outside. The change is due primarily to the amount of water vapor content. This index of refraction change will cause the ray to bend as it passes obliquely through this interface. Extremely large fluctuations, in apparent line-of-sight, can be caused by heavy cloud formations, such as thunderheads, because of both the longer path length through the cloud and the high index of refraction inside such clouds. Heavy cloud formations, when present, may very well be the principal limitation on the accuracy of radars which are used to measure the angle of arrival of electromagnetic waves.

Another limitation of radio systems is the fluctuation in phase as the electromagnetic waves pass through the ionosphere. Again, as in the tropospheric case, it is found that the mean index of refraction can be corrected out approximately, but this may vary with the season and time of day, as well as with solar activity. As is well known from recent experience in the field of radio astronomy, fluctuations in this index also occur. Measurements of angular fluctuation in the apparent position of the radio stars indicate that turbulence exists similar to the tropospheric type but with a much larger scale length. In addition to these relatively mild fluctuations, there is a possibility of Sporadic E-layers. These layers cause large variations of the refractive index as a function of position over the earth and give rise to time fluctuations as the object being tracked moves through the sky.

Fortunately, the ionospheric disturbance is highly frequency-dependent. The mean index is given by the formula

$$n = [1 - (f_0/f)^2]^{1/2}$$

where f is the frequency of the radio wave being used and f_0 the ionospheric plasma frequency. It is clear

* The radio guidance equipment is being supplied by General Electric, Burroughs, Bell Telephone, and Univac Division of Sperry Rand, with supporting research by the National Bureau of Standards, Stanford Research Institute, and Naval Research Laboratories.

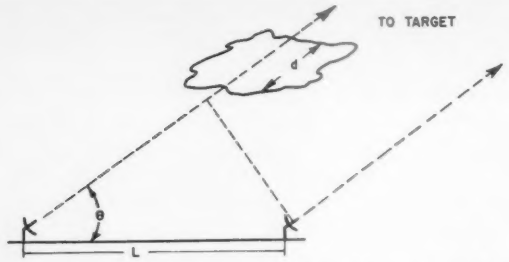

FIG. 3. Illustration of the effect of a cloud in the line-of-sight.

that the choice of a suitably high frequency will minimize the effect of the ionosphere. Too high a frequency, of course, gives trouble from atmospheric absorption and rain attenuation.

There is one technique which may be used to improve the system accuracy in the presence of tropospheric and ionospheric scatterings. It is possible to increase the baseline of the phase-difference measuring device to be used. Since the apparent angle of arrival is approximately equal to the actual phase difference (measured in wavelengths) divided by the baseline, one can make the baseline large compared to the scale of the fluctuations causing the difficulty—for example (see Fig. 3), if d is the cloud dimension and $n = 1 + \Delta n$ the index of refraction, then the error of the angle of arrival using a baseline length L is approximately equal to $d\Delta n/L$, provided the cloud appears in the line-of-sight through only one of the phase-measuring devices. It can be seen from this crude picture that, in principle, if the object being tracked is far enough away and if the baseline is made sufficiently long, propagation errors can be made very small. The limitation is again a practical one: the longer the baseline used, the more complex the equipment becomes, thereby increasing the cost, complexity, and operational difficulty, and presumably decreasing the reliability. Again, a choice must be made to balance suitably all the factors involved.

There is another effect which must be considered when radio guidance is used. Radio waves when propagated through highly ionized gases tend to be highly absorbed by the free electrons generated by the high-temperature gases. During the guided portion of the flight, of course, all engines are in operation, and, unless special precautions are taken, it may be necessary to transmit radio waves through the flame to the ground station. In the case of missiles which must be operated at very high altitudes, the flame is expanded into a vacuum, resulting in a flame shape which is more or less conical than cylindrical, thereby aggravating the problem of transmitting rearward. Propagation of the radio waves through the flame may cause both serious attenuation and change in refractive index. It is rather difficult to assess accurately the value of electron density in typical high-temperature rocket exhaust gases—and especially the manner in which it will vary from engine to engine as the fuel characteristics are changed or as various impurities are encountered. Efforts to reduce this effect vary with the case considered, but several precautions that can be made are:

(1) Avoid tracking the missile through the densest portions of the flame.

(2) Proper choice of the radio frequency according to the particular flame used may solve the difficulty since the attenuation and propagation anomalies are quite sensitive to frequency.

(3) Careful quality control of the fuel and of the fuel-oxidizer mixture ratio helps to minimize the effect, but, of course, this may cause undue complexity in the propulsion system and in the logistics of supplying propulsion ingredients.

(To be continued next month)

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Radio Navaids *(Continued from page 49)*

and long-range navigation, they are not properly covered in this article.

Long-range radio Navaids are composed of only a few basic ingredients. Signals are radiated from antenna towers on the ground in such a way as to produce lines of position over the earth. Most of these systems employ phase measurement in the receiving equipment to display the location of the receiver relative to these lines of position. The systems vary in number and spacing of antennas used on the ground, the choice of operating frequency, and the character of any special modulations employed. From these different factors, the various systems are assembled. Each of them has qualities of merit, and, in one form or another, these radio ground-based aids will provide guidance to high-speed long-range flight operations.

"With the increasing complexity of missions,
the autonavigator must assume a large portion of the flight burden
and thus must possess special purpose features
providing adaptability to various types of missions."

Multipurpose Automatic Navigator

Barry J. Baron and Rodney W. Unold
Ford Instrument Company
Division of Sperry Rand Corporation

With the advent of high-speed multipurpose airborne vehicles, the problem of guidance has grown to enormous proportions. A guidance system consisting of primary information sensors, computer system, and autopilot is presently a must on modern jet aircraft. The pilot can no longer serve as one of the components in the navigation system as he must spend all available time in the accomplishment of his mission. The navigation system primarily must be completely automatic, capable of flying the aircraft to a predetermined destination, capable of indicating present position information continuously, and capable of correcting present position information at any time. The navigation system must maintain a high degree of reliability and be easily accessible for all levels of maintenance, reducing inoperative time to a minimum. With the increasing complexity of missions, the autonavigator must assume a larger portion of the flight burden and thus must possess special purpose features providing adaptability to various types of missions.

Automatic Navigation Computer set AN/ASN-7 was designed in accordance with the multipurpose philosophy. This system is capable of receiving automatic inputs of speed and heading, and, from these, generating present position and course and distance information, initial position and desired destination being set into the computer system initially. The AN/ASN-7 system provides autopilot outputs, latitude and longitude remote outputs, as well as a panel mounted display of present position, course, and distance to desired destination. One of the major problems in automatic navigators is the accumulation of position errors with time, this necessitating the incorporation of a correction device in the system. The present position storage mechanism of the AN/ASN-7 system allows for the storage of latitude and longitude changes as present position fix information is slewed into the present position circuits. On returning the system to normal operation, the stored information is inserted into the present position circuit and combined with the fix information correcting the present position computation. The electronics portions of the computer system have been completely transistorized in accordance with proved techniques for reliability. Both mechanical and electronic portions of the computer set have been designed on a subsystem basis providing easy accessibility to any part of the system, an extremely important factor in a complex system. The alternate destination facility of the AN/ASN-7 computer system enables the pilot, at any point in the flight, to set a new destination into the computer circuitry and automatically compute course and distance to this point without the loss of any instantaneous information. This extremely important function is directly applicable to several special purpose missions, enabling the computer system to automatically control the aircraft over a greater portion of the flight.

The authors are Design Engineer and Project Supervisor, respectively, in the Aeronautical Equipment Group.

The Navigation Problem

The general navigation problem consists of the integration of the north-south and east-west velocity components with respect to time, the entire computation being earth referenced. The mathematics of the problem will be briefly discussed in this section before considering the sources of the primary information and special purpose combinations of these sensors with a computer set. The symbols involved in the navigation solution are as follows:

Lai = initial latitude
Loi = initial longitude
Lap = present position latitude
Lop = present position longitude
Lad = destination latitude
Lod = destination longitude
D = distance to destination
Hgr = rhumb line course to destination
k = constant function of earth radius $(360°/2\pi r)$
Vg = ground speed

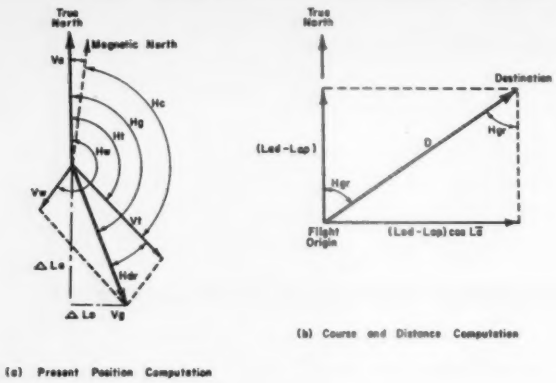


FIG. 1. The navigation problem.

Hg = ground track
Vt = true air speed
Ht = true aircraft heading
Vw = wind force
Hw = wind heading
Va = variation, angle differentiating magnetic north from true north
t = time
h = altitude

The geometrical aspects of the navigation problem are depicted in Fig. 1, the present position solution in (a) and the course and distance solution in (b).

Present position may be expressed as:

$$Lap = Lai + k \int Vg \cos Hg \, dt$$
$$Lop = Loi + k \int Vg \sin Hg \sec Lap \, dt$$

This solution consists of the integration of ground speed information directly, and thus is termed, "Ground Speed Mode" solution.

A second expression for present position may be generated utilizing the available air speed and wind information.

$$Lap = Lai + k \int (Vt \cos Ht + Vw \cos Hw) dt$$
$$Lop = Loi + k \int (Vt \sin Ht + Vw \sin Hw) \sec Lap \, dt$$

This solution is termed "Air Speed Wind Mode" solution.

The rhumb line course and distance solution is immediately obtainable from Fig. 1(b).

$$D = (Lod - Lop) \cos L\bar{a} \sin Hgr + (Lad - Lap) \cos Hgr$$

where $\cos L\bar{a} = \Delta La / \int \sec La \, dLa$

$$\tan Hgr = (Lod - Lop) \cos L\bar{a} / (Lad - Lap)$$

AUTOMATIC NAVIGATION COMPUTER SET AN/ASN-7

Automatic Navigation Computer Set AN/ASN-7 performs the two basic computations indicated in Fig. 1 by analog methods. The computer system is packaged extremely tightly to keep volume to a minimum, Fig. 2 illustrating the packaging techniques employed in the course and distance portion of the system. A single panel mounted control unit, Fig. 3, provides slewing mechanisms for latitude, longitude, variation, wind speed, and wind direction. The latitude and longitude displays in the upper portion of the control unit are time shared between present position and destination. Through this circuitry, including the present position and destination storage mechanisms located in the course and distance computer, present position reset and alternate destination insertion may be accomplished. Variation, which is the angle between true and magnetic north at any point on the earth's surface, is available either manually or automatically, the variation counter in the control unit being utilized in either mode. Wind information is inserted into the control unit manually and displayed on the wind-speed and wind-direction counters. A wind memory computer has been designed by Ford Instrument Company to provide automatic wind information based upon ground speed, true air speed, true aircraft heading, and drift angle information display to utilize the same counters as the manual wind information. The course and distance indicator is the only other panel mounted instrument in the computer set. Distance to destination, desired course to destination, and ground track are displayed in the course and distance indicator. The difference between desired course and ground track forms a heading error which may be corrected manually or automatically by turning the aircraft into the desired course and reducing the indicated heading error to zero. The automatic correction of aircraft heading requires an autopilot system, the autopilot closing the navigation loop.

It is now apparent that the navigation computer set must receive the following information, in analog form, from primary sensing equipment:

(a) System operation in ground speed mode.
  (1) Ground speed and drift angle from radar set.
  (2) Magnetic heading from compass system.
(b) System operation in air speed wind mode.
  (1) True air speed from true air speed computer or central air data computer system.
  (2) Magnetic heading from compass system.

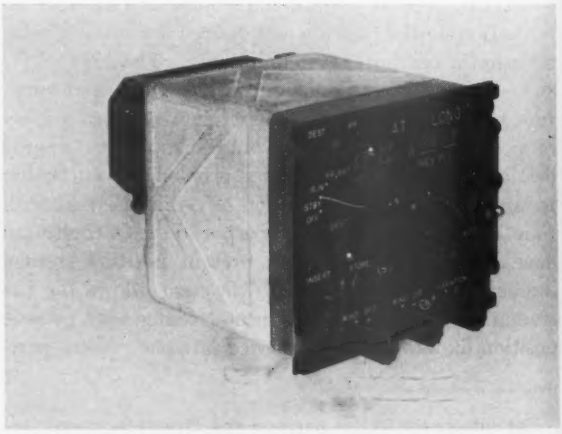


FIG. 2. Computer control C1317/ASN-7.

Automatic radar navigation systems utilizing the equipment outlined in this section will be discussed in the ensuing sections.

Automatic Radar Navigation Systems

A general closed-loop automatic radar navigator is illustrated in Fig. 4, sensor and autopilot requirements depending upon the mission. A system could be created for almost any tactical requirement, the practical limits being accuracy, range, and tolerable weight.

The ultra precise radar navigation system stresses accuracy. The accuracy requirement necessitates the use of a doppler radar sensor of the order of accuracy of the APN-81 or APN-116 and a compass system of the order of accuracy of the C-12. Combining these primary sensors with the AN/ASN-7 computer system, 67 per cent probability accuracy values of 0.98 per cent distance traveled could be achieved in the ground-speed mode solution. The air-speed wind mode would require a C-12 type heading reference, central air data computer of the same order of accuracy as the MG-1 and FICo wind memory computer. Using these sensors with an AN/ASN-7 computer system, accuracies in the order of 1.8 per cent distance traveled could be achieved assuming constant wind for 67 per cent probability of occurrence. In recent years, gyro device heading references have become prominent in airborne navigation. They range from simple directional gyros to the complex all-attitude multiple-gyro platform systems. The state of the art limits the static accuracy of these devices to approximately two tenths of a degree with an additional error attributed to gyro drift. The C-12 type pendulus magnetic heading sensor with vertical gyro weighs a great deal less than many of the gyro platform systems and is thus desirable for aircraft incapable of rapid maneuvering with relatively straight missions. To meet the needs of the highly maneuverable aircraft, where the weight requirement permits it, a gyro platform device may be used for the heading sensing element. It is probable that as the state of the gyro art advances, eventually the weight, volume, and price of the gyro device will approach that of the magnetic compass system making the gyro heading reference much more desirable for use in aircraft automatic navigators.

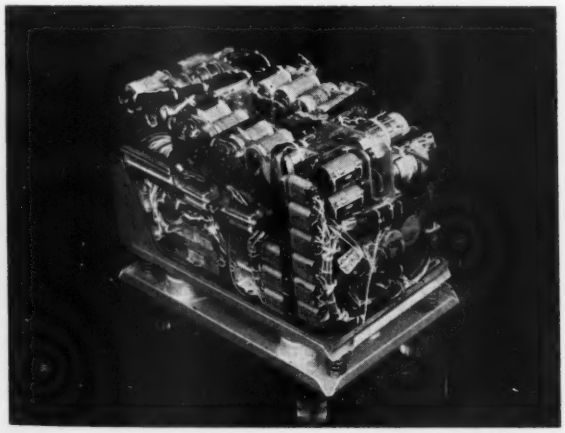


Fig. 3. Course and distance computer CP-289/ASN-7.

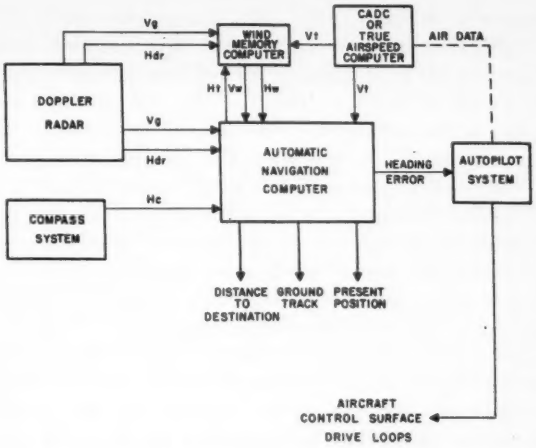


Fig. 4. Block diagram of automatic radar navigator.

Medium accuracy navigation systems are required for both civilian and government aircraft. In general, these systems contain lighter weight, less accurate sensing equipment with a small reduction in the amount of automatic information available. A C-12 type heading reference, APN-102 type doppler radar, and synchrotel true air-speed source might be utilized to provide data for the computer portion of the system. This system would be lighter than the very precise systems but also less accurate. The estimated 67 per cent probability accuracy for a system of this type in the ground speed mode would be approximately 1.3 per cent of distance traveled. A system of this type would be utilized on aircraft whose mission calls for a relatively good accuracy but whose weight limit precludes the use of the heavier, more accurate equipment.

Coarse, lightweight systems are utilized in fighter type aircraft where the navigator weight and volume requirement becomes extremely critical. This class of aircraft is highly maneuverable and as such introduce sensing equipment difficulties. For accurate information during heavy maneuvering, doppler radar antennas must be stabilized with respect to roll, pitch, and yaw, and pendulous type magnetic heading sensors must be compensated for acceleration effects. The utilization of sensor correction devices would bring system weight into the higher echelons of the medium accuracy class. The coarse navigator thus takes a beating in accuracy during heavy maneuvering because of the inability of the sensing equipment to operate at aircraft maneuvering profiles. This, however, is acceptable since the navigation system is usually not utilized during heavy maneuvering. This navigation system must get the aircraft to a specified point fairly accurately and then after heavy maneuvering indicate roughly aircraft position so that the return to base portion of the mission may be accomplished as efficiently as possible. The coarse navigation system might include a C-10, 11-type

magnetic compass, APN-102 class doppler radar, and synchrotel true air-speed source. Ground-speed mode accuracy for approximately 67 per cent probability for a system of this type utilizing the AN/ASN-7 computer system would be in the order of 1.7 per cent distance traveled. As was indicated, any aircraft maneuvering exceeding sensor limits would cause deterioration of system accuracy. In cases where the navigator requirements permit the installation of a wind memory computer, the doppler mode error caused by exceeding system sensor limits may be greatly reduced by switching the system from the ground-speed mode to the air-speed wind mode, using a true air-speed source, magnetic compass, and last-remembered wind information to generate the navigation solution for this mode. Sensor errors will not be completely eradicated in this manner as the heading reference and air-speed source will experience high accelerations causing inaccuracies; however, the accuracy of this system for a flight including heavy maneuvering will be much better than that of the system lacking wind memory. Angle of attack will introduce additional sensor errors particularlyin the coarse true air-speed source. This effect is minimized when a central air data computer system is utilized in the navigation equipment, angle of attack corrections being automatically applied to the true air-speed output. Manual wind information may replace wind memory in the generation of the air-speed wind mode solution, this system exhibiting a greater degree of inaccuracy than the automatic wind system. The high and medium accuracy systems will carry wind memory, or at least manual wind inputs as part of the standard navigation equipment providing the air-speed wind backup mode.

Minimum function systems, generally quite coarse, are utilized by short range aircraft and in some cases by high-speed fighter aircraft where the stringent weight requirement precludes the use of any other system. In general, this system will provide heading deviation from a desired course and distance along and across the desired course.

A point of interest in the overall automatic navigation system is the stability problem encountered. The overall navigator must be compatible with the aerodynamic characteristics of the aircraft as the airframe is an integral part of the closed loop system. In many instances, navigation information, in particular radar information, is supplied to the remainder of the system as noisy signals requiring the use of smoothing functions in the system. If the stability problem is not accounted for, the aircraft may experience oscillations rendering it incapable of completing the required mission.

Up to this point, not much has been said concerning special purpose missions. The following section will describe several missions and consider the multipurpose computer systems that may be utilized for their completion.

Special Purpose Navigation

Special purpose navigation information is generally obtained by performing modifications on existing computer systems. The automatic radar navigation system, while primarily providing the basic navigation computations, also provides most special purpose information, this latter information not always being easily obtainable. This method of obtaining the required information is extremely advantageous as the additional functions are provided with a minimum increase in system weight, volume, and, usually, cost.

During specific missions, grid-type outputs are desirable, in particular for radarscope stabilization. Grid outputs or what are often referred to as the X-Y coordinate outputs, consist of north-south and east-west mileage values rather than the normal latitude and longitude outputs. The required functions are generally obtained by placing potentiometers on the computer component mileage shafts prior to the angular conversion, the required output scales being obtained by applying specific excitation voltages to the potentiometers. Switching circuitry is usually necessary in a modification of this type, the complexity dependent upon the mission requirements. This modification will generally cause a small increase in system weight and volume, but will not cause any sizable decrease in primary navigation accuracy.

Tactical requirements may demand better than normal navigation accuracy during certain portions of a flight, normal accuracy being inadequate. An approach to this problem is the time sharing of the navigator as a long and short range system by controlling scale values of the computing elements. A decrease in the computing element scale values will cause an increase in system accuracy over normal operational accuracy. There are, of course, specific accuracy limits beyond which this approach is of no avail, the possibility existing that the additional accuracy requirement exceeds system performance at low scale values This modification introduces difficulty because of the complexity of the switching circuitry required; however, where weight, volume, and accuracy requirements permit its utilization, the modification can be made.

Flight, and thus navigation, through the earth's polar regions has become an extremely important problem. Normal navigation computers are unable to cope with the extremely high longitude rates encountered in these areas due to the meridian convergence at the earth's poles. Longitude is dependent upon the secant of latitude and as the latitude approaches 90° north or south, the secant approaches infinity causing the longitude rate to become excessive. For navigation in these regions, it is convenient to shift the earth's poles to the equator, thus rotating the near grid arrangement that exists at the equator to the polar areas of the earth. In the navigation computation, this rotated system of axes generally referred to as transverse coordinates must be accounted for by proper coordinate referencing re-

quiring the inclusion of an adapter unit in the navigation system. Ford Instrument Company has formulated a polar heading adapter for use with an automatic navigation computer set such as the AN/ASN-7 system providing world capability for the system.

Photographic mapping and charting missions occasionally require automatic navigation information for camera image compensation. The desired information is generally a function of ground speed and altitude, these quantities to be obtained from the navigation equipment. Ground-speed information is available in the computer portion of the navigator in both the ground-speed and air-speed wind modes of operation. The altitude information for this application is generally obtained from a radar type altimeter, lesser systems utilizing the coarse altimetry equipment carried by the aircraft. The accuracy of the required ground speed/altitude function will determine the type of altimeter information needed, a radar type altimeter for precise calculations and a pressure type altimeter for coarser measurement. The desired Vg/h function may be generated directly in the computer portion of the system generally necessitating the addition of one servo loop and switching circuitry, requiring a small increase in weight and volume of this portion of the system.

The automatization of weather data may be accomplished by performing minor modifications in the automatic navigator. Wind information may be obtained relatively accurately from the system wind memory facility, the thermodynamic air parameters being supplied by the central air data computer. The navigator utilized for this type of mission would be a higher order system since both a wind memory computer and central air data computer would be necessary. The navigation and weather data computations may function simultaneously with no decrease in position accuracy.

As was previously mentioned, maintaining specific navigation accuracies over long periods of time is difficult. Time dependent errors exist in the automatic radar navigation system, these errors building up with time. In accordance with this, accuracies over long flights would tend to suffer greatest from accumulated errors in the most important portion of the mission, the target or observation area. It is thus extremely important that this effect be reduced to a minimum, the difficulty of compensating for a random type error pattern existing. The only practical method of fixing aircraft position is by referencing the aircraft to a known check point and correcting the computed aircraft position to correspond to check point position. This operation, usually referred to as position fixing, may be accomplished by various means which differ in check point selection and in type of information generated.

Radar fix information is usually the rho and theta form. A ground station picks up the aircraft on a radarscope and transmits position with respect to ground station to the aircraft fix receiving equipment. Systems falling into this category are NAVARHO and TACAN which differ primarily in the ranges involved, NAVARHO being a long range system and TACAN a short range system.

The astrotracker is a device that sights on a known star and generates aircraft position with respect to the latter. Some difficulties encountered in astrotracking are the dependence of the system upon local weather conditions and the high degree of stabilty that must be provided for the sighting device. This system depends upon tracking the reference star it is sighting on and will not function properly in clouds or atmospheric disturbances hindering visibility.

The completely manual fix consists of flying over a known position on the surface of the earth and comparing computed present position with the position of the check point. The accuracy of this method deteriorates rapidly with increasing altitude and speed rendering it useless for modern high-speed aircraft. Fix information generated in this manner might tend to be less accurate than the actual navigation computation accuracy.

In general, the navigation system of the aircraft will receive the automatic fix information, inserting it into the present position circuitry. During this insertion of information, changes in latitude and longitude are stored in the computer memory facility, to be driven into the present position circuitry at the end of the insertion phase.

As weight and volume requirements for control electronics are generally extremely stringent in aircraft, it is important that the electronic systems provide as much automatic flight coverage as possible. The automatic navigation system must assume a versatility making possible its utilization on various types of missions. From a cost standpoint, the multipurpose system holds the advantage as costly additional electronic equipment necessary to perform the auxiliary computations is eliminated. The cost, weight, and volume savings associated with systems of the type briefly described in this paper are extremely important as the use of additional armament or fire power on the aircraft may hinge upon these quantities. If the electronics weight requirement is very rigid due to engine capability or associated problems, the multipurpose system is desirable as it will provide the maximum in navigation and related information for a reasonable weight.

✦ ✦ ✦

The results are presented of an investigation of the significance of the coupling at hypersonic speeds among the three channels of an inertial navigation system due to errors in the orientation of the indicated coordinate system and errors in acceleration compensations. Reasonably simple analytical expressions are offered which can be used to determine the navigation system performance for the given conditions.

Cross Coupling in Inertial Navigation Systems

Robert E. Wilson and John B. Lewis
General Electric Company

SYMBOLS

x, y, z	= axes fixed to platform
$\epsilon_x, \epsilon_y, \epsilon_z$	= angular errors about x, y, z axes
$\delta_x, \delta_y, \delta_z$	= position errors along x, y, z axes
a_x, a_y, a_z	= total accelerations along x, y, z axes (include gravity)
v_x, v_y, v_z	= velocity components along x, y, z axes
R	= distance to the earth center
$\delta_R = -\delta_z$	= radius error
$\omega_s = \sqrt{g/R}$	= Schuler frequency, rad./sec.
$\omega_v = V_x/R$	= craft angular velocity over earth
Δ	= gyro drift angle
g	= gravity at sea level
$n = a_z/g = 1 - (\omega_v/\omega_s)^2$	= normal load factor
$\omega_1, \omega_2, \omega_3, \alpha, a_1, a_2$	= system parameters defined in Fig. 1

THE EXTENSION of aircraft speeds to the hypersonic range makes the linear accelerations due to slightly curved flight paths change from small but significant effects to major design parameters in inertial navigation systems. It is the purpose of this paper therefore to show how the navigation of hypersonic aircraft over a nearly spherical earth involves significant interaction or coupling. This coupling occurs between lateral (cross range) errors and azimuth errors and also between longitudinal (range) errors and vertical channel (velocity and altitude) errors.

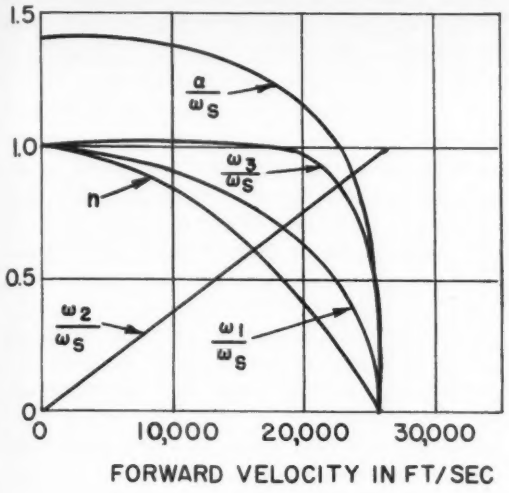
The major cause of both types of coupling is the relatively high angular velocity of the aircraft about the center of the earth. Assuming essentially constant altitude, it is found that normal load factor, defined here as the ratio of total vertical acceleration to sea-level gravity ($n = a_z/g$), is sufficient to describe the coupling parameters completely. Thus the same normal load factor which is so useful for conventional maneuvering flight is now useful for essentially straight and level hypersonic flight. Several of the relationships between primary system parameters and normal load factor are summarized in Fig. 1.

Mr. Wilson and Mr. Lewis are Development Engineers in the Light Military Electronic Equipment Department.

System Description and Assumptions

In order to demonstrate these coupling effects, a simple navigation system will be used. In analyzing this system, many factors and sources of errors which are known to be important in the uncoupled case but which do not change the essence of the coupling effects to be demonstrated here will be neglected. This simplification has been verified by extensive analog computer investigations. The navigation system considered is assumed to be a pure inertial, undamped, Schuler-tuned system, with its platform maintained perpendicular to the local vertical. A great circle flight is assumed with axes oriented with respect to gravity and forward speed as shown in Fig. 2.

With these assumptions, the two types of coupling can be treated independently since the lateral-azimuth error equations are essentially independent of the longitudinal-vertical error equations. This situation is analogous to the conventional treatment of the aircraft equations of motion in that the two sets of equations are independent. The error equations are summarized in Tables 1 and 2. It may be noted further that the three equations defining the lateral-azimuth coupling are analogous to the aircraft roll, yaw, and side force equations and that the three equations defining the longitudinal-vertical coupling are analogous to the aircraft pitch, lift, and drag equations. The major difference, however, is that the navigation reference axes are aligned with the platform, whereas, in the aircraft equa-



Lateral-azimuth coupling $\delta_y = F(\omega_1, \omega_2)$

Longitudinal-vertical coupling $\delta_x = F(\omega_3, \alpha)$

$$\omega_1/\omega_s = \sqrt{n};\ a_1 = \omega_3/\omega_s = \sqrt{(n/2)\ [-1 + \sqrt{(16/n) - 7}]}$$

$$\omega_2/\omega_s = \sqrt{1 - n};\ a_2 = \alpha/\omega_s = \sqrt{(n/2)\ [1 + \sqrt{(16/n) - 7}]}$$

$$n = 1 - (V_x^2/Rg)$$

FIG. 1. Relationship between system parameters and normal load factor n.

tions of motion, the reference axes are normally aligned with the airframe.

In considering both types of coupling, it is found that, if the aircraft rates of change of velocity are properly accounted for, considerable simplification in the solutions of the error equations is possible. Analog computer studies have verified that, for rates of change of velocity of the order of $0.2g$ or less and for times of flight of about one-half hour, the rate of change of velocity can be neglected. For longer times of flight, the addition of a simple term proportional to forward acceleration (or deceleration) is sufficient to give reasonably accurate solutions. However, it is cautioned that the initial conditions associated with obtaining the hypersonic velocities must be carefully considered in order to obtain the correct solutions. In practice, the acceleration required to obtain the hypersonic velocities is not critical unless extended over a time which is significant compared with the periods of the oscillations involved. Hence it is possible to assume a step velocity in obtaining initial conditions and then to use average speed for the duration of the mission. The use of average speed in missions which involve speed changes corresponding to a few tenths of a g for as long as one hour has also been verified by analog computer results and gives excellent approximations to the more exact solutions.

An important point to note is that, when flights occur in a direction other than approximately parallel to one of the major axes of the table, azimuth motion couples with the longitudinal channel, as well as with the lateral channel, and that the vertical motion couples with platform lateral motion, as well as the longitudinal motion. In this case, the equations become more complicated.

A final assumption is made that the Coriolis accelerations associated with earth rate are negligible. This is approximately true for hypersonic flight where the aircraft forward speeds cause an angular velocity of the aircraft about the center of the earth much larger than the angular velocity of the earth. It is also noted that, in the type of inertial navigation system assumed, the range is obtained by simple integration of the velocity obtained from the Schuler loop.

Nature of Results

In general, there are three types of forcing function which are commonly treated in error analyses of inertial navigation systems. One example for each is used for both types of coupling. The types selected are gyro drift rate, initial tilt error, and initial velocity errors. These forcing functions cause errors in platform tilt,

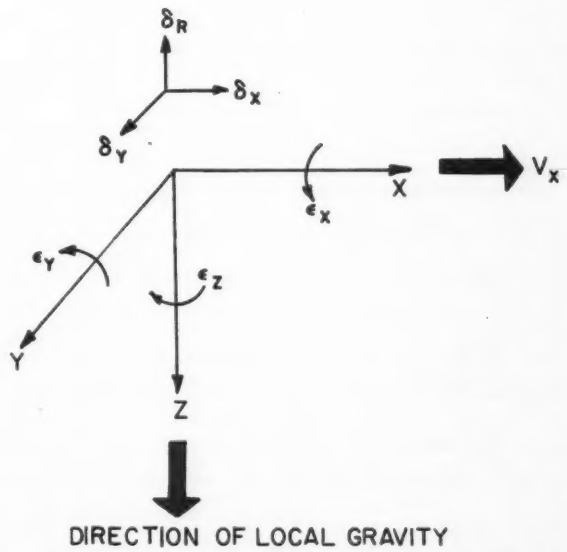


FIG. 2. Reference system. (See section on Symbols for definitions.)

indicated velocities, and indicated position. For this paper only the errors in indicated position—namely, cross range and range errors—will be shown.

Lateral-Azimuth Coupling

The coupling between the azimuth error and the cross range error becomes important at hypersonic speeds because, when an azimuth error exists, the high angular velocity of the aircraft about the center of the earth causes a significant component of angular rate about the X-axis. Also, any platform tilt about the X-axis causes a component of angular rate about the vertical axis which is also proportional to the high velocity and this produces an azimuth error.

The coupling effects can be investigated by solving the equations of Table 1 simultaneously. Solutions for each independent error source for the conditions of the example described above have been obtained, and the resulting expressions for the cross range error (δ_y) are also given in Table 1. It can be seen that in the column marked "coupled" for the gyro drift rate and initial angle error responses, two modes of undamped error oscillation result. One mode is of frequency $\omega_1 = \sqrt{n}\omega_s$, which is the usual Schuler frequency modified by the value of n, as shown in Fig. 1. The other mode is of frequency $\omega_2 = \sqrt{1-n}\omega_s = V_x/R$, which is the angular velocity of the aircraft about the center of the earth. This form of error response associated with azimuth error is also characteristic of gyrocompassing systems where, for very low speed craft, the earth rate is the significant frequency rather than the frequency $\omega_2 = V_x/R$. For conventional aircraft speeds involving a longer time of flight, a frequency which is a combination of earth rate and craft motion is used.

As the aircraft speed is reduced, the coupling effects become less important (ω_2 approaches zero). The limiting error responses for the "uncoupled" condition are given in Table 1; these are the usual error equations.

It should be noted that, in the case of azimuth misalignment, it is necessary to include a term in the "coupled" solution to account for the initial velocity error which is inherent in attaining a hypersonic speed. The presence of an azimuth error during the initial acceleration period makes the magnitude of the initial velocity error large enough to be of significance in the constant velocity flight assumed in this paper. Also,

TABLE 1
Error Equations

Tilt	$\ddot{\varepsilon}_x - \frac{a_z}{R}\varepsilon_x - \frac{V_x}{R}\dot{\varepsilon}_z = \ddot{\Delta}_x$	(1)
Lateral	$\ddot{\delta}_y + a_x\varepsilon_z - \varepsilon_x a_z = 0$	(2)
Azimuth	$\dot{\varepsilon}_z + \frac{V_x}{R}\varepsilon_x - \frac{V_x}{R^2}\delta_y = \ddot{\Delta}_z$	(3)

Cross Range Error Responses (δ_y)

Error Source	Uncoupled (n 1)	Coupled ($n \neq .5$)
x-gyro drift	$-\frac{\dot{\Delta}_x R}{\omega_s}(\omega_s t - \text{Sin}\ \omega_s t)$	$\frac{\dot{\Delta}_x R}{\omega_s(2n-1)}\left[\sqrt{n}\,\text{Sin}\,\sqrt{n}\,\omega_s t - \frac{n}{\sqrt{1-n}}\,\text{Sin}\,\sqrt{1-n}\,\omega_s t\right]$
z-gyro drift	$* -\dot{\Delta}_z R\,(\sqrt{1-n}\,\omega_s)\frac{t^2}{2}$	$\frac{\dot{\Delta}_z R}{\sqrt{1-n}\,\omega_s}\left[1 - \frac{n}{2n-1}\,\text{Cos}\sqrt{1-n}\,\omega_s t + \frac{(1-n)}{2n-1}\,\text{Cos}\sqrt{n}\,\omega_s t\right]$
initial platform tilt	$-\varepsilon_{x_0} R(1 - \text{Cos}\,\omega_s t)$	$\frac{-\varepsilon_{x_0} R}{2n-1}\left[\text{Cos}\,\sqrt{1-n}\,\omega_s t - \text{Cos}\,\sqrt{n}\,\omega_s t\right]$
initial azimuth misalignment	$* -\varepsilon_{z_0} R\sqrt{1-n}\,\omega_s t$	$\frac{\varepsilon_{z_0} R\sqrt{n}}{(2n-1)}\left[\sqrt{1-n}\,\text{Sin}\,\sqrt{n}\,\omega_s t - \sqrt{n}\,\text{Sin}\,\sqrt{1-n}\,\omega_s t\right] - \frac{\varepsilon_{z_0} R\sqrt{1-n}}{n}\,\text{Sin}\sqrt{n}\,\omega_s t$
initial lateral velocity error	$\frac{\dot{\delta}_{y_0}}{\omega_s}\,\text{Sin}\,\omega_s t$	$\frac{\dot{\delta}_{y_0}}{\sqrt{n}\,\omega_s}\,\text{Sin}\,\sqrt{n}\,\omega_s t$

* Approximate (neglects platform tilt). These expressions may be written also:

$-\frac{\dot{\Delta}_z}{2}$ (Range) t and $-\varepsilon_{z_0}$ (Range) respectively.

TABLE 2
Error Equations

Tilt $$\ddot{\varepsilon}_y - \frac{a_z}{R}\varepsilon_y - \frac{2\dot{V}_x\dot{\delta}_R}{R^2} - \frac{\dot{V}_x\delta_R}{R^2} = \ddot{\Delta}_y \quad (4)$$

Longitudinal $$\ddot{\delta}_x + a_z\varepsilon_y + \frac{\dot{V}_x\dot{\delta}_R}{R} = 0 \quad (5)$$

Vertical $$\ddot{\delta}_R + a_x\varepsilon_y - \frac{2\dot{\delta}_x\dot{V}_x}{R} - \frac{2g}{R}\delta_R = 0 \quad (6)$$

Range Error Response (δ_x)

Error Source	Uncoupled (n = 1)	Coupled
y-gyro drift	$\frac{\dot{\Delta}_y R}{\omega_s}(\omega_s t - \text{Sin}\,\omega_s t)$	$\dot{\Delta}_y R\left\{\frac{t}{2-n} - \frac{n}{\omega_s(a_1^2+a_2^2)}\left[\left(\frac{2+a_1^2}{a_1^3}\right)\text{Sin}\,a_1\omega_s t + \frac{2-a_2^2}{a_2^3}\text{Sinh}\,a_2\omega_s t\right]\right\}$
initial platform tilt	$\varepsilon_{y_o} R(1 - \text{Cos}\,\omega_s t)$	$\varepsilon_{y_o} R\left\{\frac{1}{2-n} - \frac{n}{(a_1^2+a_2^2)}\left[\frac{2+a_1^2}{a_1^2}\text{Cos}\,a_1\omega_s t + \frac{2-a_2^2}{a_2^2}\text{Cosh}\,a_2\omega_s t\right]\right\}$
initial vertical velocity error	$\frac{\dot{\delta}_{R_o}\sqrt{1-n}}{2\omega_s}\left\{1 - \frac{4}{3}\text{Cos}\,\omega_s t + \frac{1}{3}\text{Cosh}\sqrt{2}\,\omega_s t\right\}$	$\frac{\dot{\delta}_{R_o}\sqrt{1-n}}{2(2-n)\omega_s}\left\{1 - \frac{1}{n(a_1^2+a_2^2)}\left[a_2^4\text{Cos}\,a_1\omega_s t - a_1^4\text{Cosh}\,a_2\omega_s t\right]\right\}$
initial longitudinal velocity error	$\frac{\dot{\delta}_{x_o}}{\omega_s}\text{Sin}\,\omega_s t$	$\frac{\dot{\delta}_{x_o}}{\omega_s(a_1^2+a_2^2)}\left\{\frac{2+a_1^2}{a_1}\text{Sin}\,a_1\omega_s t - \frac{2-a_2^2}{a_2}\text{Sinh}\,a_2\omega_s t\right\}$

since the effect of longitudinal acceleration during the flight is not included, the cross range error due to initial lateral velocity error is of the same form as that for the coupled condition. This is so because the platform tilt equals the angle which the aircraft has traveled about the earth. Inspection of Eq. (3) shows that in this case no azimuth error will occur.

Examples

The cross range error responses for typical error sources are shown in Fig. 3 for several values of hypersonic speed. In Fig. 3a, for gyro drift about the longitudinal axis, the effect of the coupling for the times shown is a reduction in the magnitude of the cross range error when compared to the "uncoupled" response. This is also typical of the cross coupling effects in Figs. 3b to 3d. The difference between the curve for $n = 1$ and the "uncoupled" curve for $n = 0.75$ is that a value of $\sqrt{n}\omega_s$ is used instead of ω_s. It can be seen that, for flights of about three quarters of an hour or less, the difference between the two curves for $n = 0.75$ is small, but, for longer flight times, the effect of the coupling becomes important.

Figs. 3b, 3c, and 3d show the responses for azimuth gyro drift, initial tilt about the longitudinal axis, and initial azimuth misalignment. In Fig. 3d, it can be seen that the change from $n = 0.75$ to $n = 0.25$ results in an increase in cross range error rather than a decrease as in Figs. 3a to 3c. The reason is the important extra term due to initial velocity error discussed above.

Although in general the differences between the "uncoupled" and "coupled" responses become significant for larger times, it is important to keep in mind that, if range rather than time of flight is considered, the various speeds would result in considerably different times of flight and the relative importance of the coupling effects would be changed.

LONGITUDINAL-VERTICAL CHANNEL COUPLING

There are three major effects which cause coupling between the longitudinal and vertical channels. These are indicated in Fig. 4. Two of these are of prime importance for hypersonic speeds, and the third is important at all speeds. The most significant factor is that an error in indicated forward speed results in an error in computed centripetal acceleration which, in turn, causes an error in the vertical channel. This error is in the indicated rate of change of vertical velocity. The second effect is that an error in indicated vertical velocity forces an error in computed forward acceleration proportional to forward velocity. This error then results in an error in forward velocity and platform torquing rate. The third effect is an error in vertical position (radius). This results in the familiar error in Schuler-loop gain which is included in the conventional "uncoupled" treatment. Also shown in Fig. 4 is the familiar undamped oscillatory mode of the longitudinal channel. The vertical channel, however, has a divergent mode which is due to the use of indicated

radius to compute gravity compensation. These two modes are evident in the solutions shown in Table 2.

Even in the treatment of conventional "uncoupled" error equations, it is well known that any error sources in an inertial vertical channel cause a divergence which is unacceptable in the navigation system because of the large radius error which results. This divergence is usually prevented by monitoring the radius information primarily through the use of barometric altitude. For the hypersonic aircraft, errors in radius still cause errors in range proportional to the speed, but much more significant is the fact that errors in vertical velocity are extremely critical. In addition, for hypersonic vehicles, continuous external monitoring information for the vertical channel may not be readily available. This is because barometric altitude is extremely difficult to obtain at the speeds and required altitudes of hypersonic flight, and radar altitude information introduces terrain errors in the radius which must be eliminated. It thus becomes desirable to minimize the requirements for monitoring the vertical channel. Considering this, the method presented in this paper can be useful in determining the accuracy required of the external information and the frequency with which it should be used to correct vertical channel errors.

KEY FOR FIGS. 3 AND 5

n	V (ft./sec.)
1	0
0.75	13,000
0.25	23,000

Examples

Fig. 5 shows the nature of the coupling for range errors resulting from three error sources in the horizontal channel and one error source in the vertical channel. It is seen that, for each of the three basic types of error source in the horizontal channel, the error in range is initially less than the "uncoupled" error but that it finally diverges. The higher the aircraft forward speed, the greater the initial reduction in error and the sooner this divergence becomes critical. For errors arising in the vertical channel, a rapid divergence occurs early in the flight as expected.

A point which is not so obvious is that the error sources arising in the horizontal channel always result

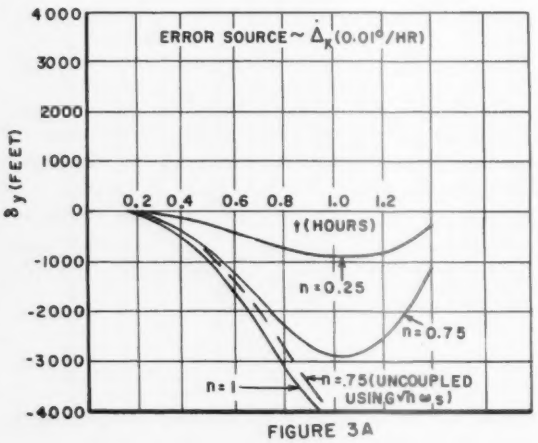


FIGURE 3A

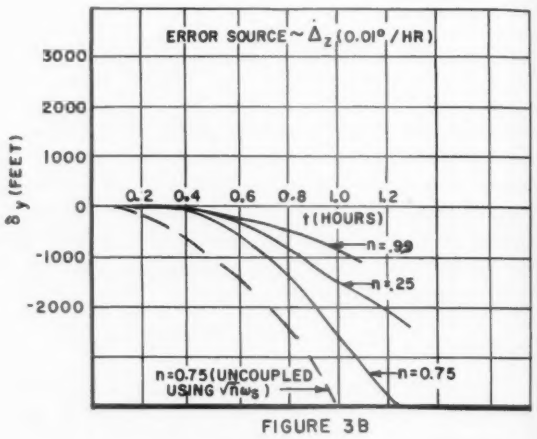


FIGURE 3B

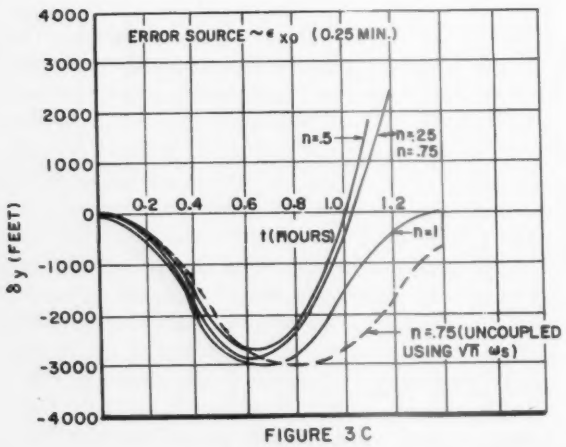


FIGURE 3C

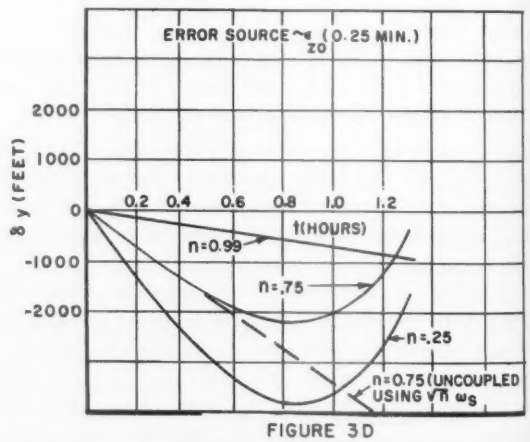


FIGURE 3D

FIG. 3. Cross range errors for coupling between lateral and azimuth channels.

in initial range errors which are opposite in direction to those caused by coupling with the vertical channel. Hence, in coupling the various sources of errors, it is found that the divergence rate is not as great as might first be expected and that it is therefore possible to increase the time required between correcting the vertical channel errors. It is also emphasized that, in correcting the vertical channel errors, it is important to correct both vertical velocity and radius in order to minimize the frequency of using external information in the vertical channel.

Only one type of error source in the vertical channel is shown—namely, initial error in vertical velocity. Perhaps even more important is an error in vertical accelerometer bias, but this error causes range errors which are similar to those already discussed, and the major points made above still hold.

Conclusion

The results presented have shown that certain coupling effects are significant in inertial navigation systems used at hypersonic speeds. Typically simple expressions have been given for estimating distance error responses in terms of the normal load factor in the case of the example of a constant velocity flight.

For lateral-azimuth coupling, it is found that:

(1) In general, the coupling effects tend to reduce the cross range errors over the one-hour flight times considered.

(2) An initial velocity error due to initial acceleration is important in the case of initial azimuth misalignment.

(*Continued on page 80*)

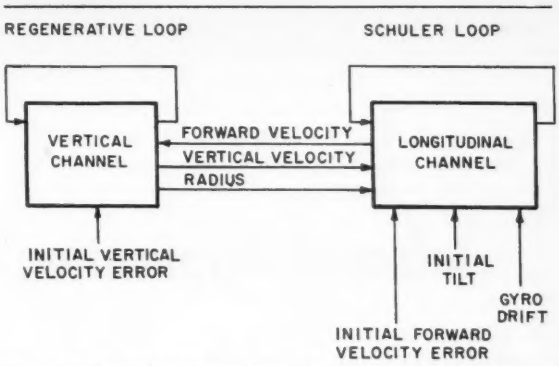


FIG. 4. General nature of coupling between longitudinal and vertical channels.

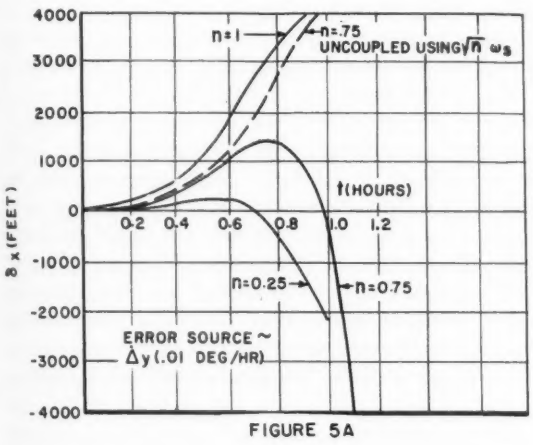


FIGURE 5A

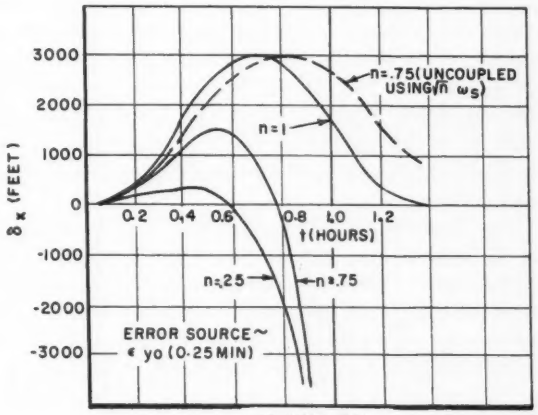


FIGURE 5B

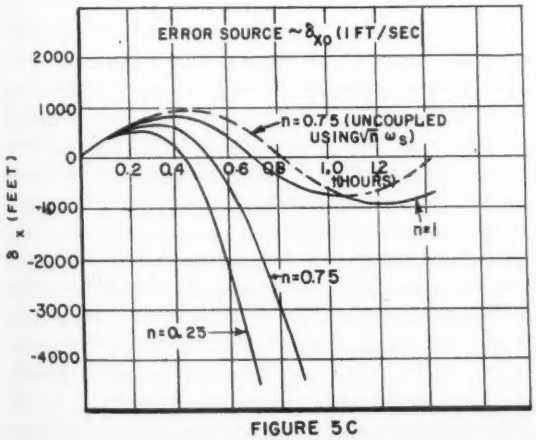


FIGURE 5C

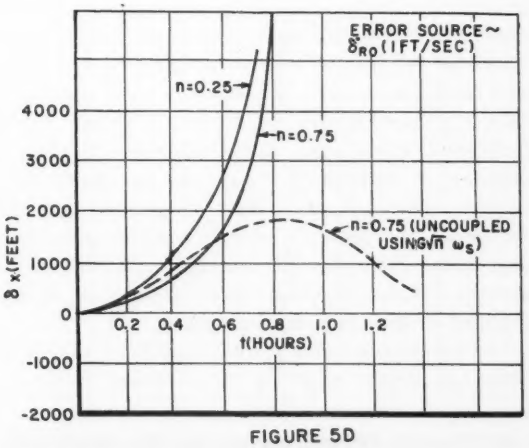


FIGURE 5D

FIG. 5. Range errors for coupling between vertical and longitudinal channels.

The characteristics and techniques of the comparatively new infrared technology discussed in this paper offer promise of appreciable increase in long-range detection capability in the future.

Infrared Application to Guidance and Control

R. W. Powell and W. M. Kauffman
Aerojet-General Corporation

AT THE PRESENT STATE of man's knowledge, the long-range detection of aircraft is accomplished almost exclusively by means of electromagnetic radiation—visible light, radio (or radar), and infrared (or "heat") radiation. Until recently, the exploitation of infrared radiation proceeded slowly. However, near the end of World War II, new types of infrared detectors were developed which largely overcame the earlier problem of low sensitivity and slow response.

Long-range detection systems are either cooperative (with the detected vehicle carrying a beacon to aid the detection station) or noncooperative (with no special provisions made in the detected vehicle to aid the detector). While noncooperative detection is more difficult, it is more reliable. This is true even in nonmilitary applications since beacon failure destroys any cooperative scheme.

Fig. 1 shows that noncooperative visual equipment is semiactive—i.e., the detection set requires an external source, such as the sun or a searchlight, to illuminate the target. Noncooperative radio or radar equipment may be either semiactive or fully active. As shown in Fig. 1, most radar equipment is fully active—i.e., the detection set "sees" the target by detecting the target-reflected energy that originally was emitted by a beacon near the detector and interconnected to it. In fact, most radar sets use the same antenna to transmit the beacon energy and to receive the reflected signal.

One of the unique features of infrared (IR) detection is that it is entirely passive—i.e., it operates by detecting the radiation emitted by the target. All objects with temperatures above absolute zero emit IR radiation of various intensities and at various wavelengths, depending upon their temperature and their surface characteristics. Except in a few special cases, very little visible or radar energy is emitted. Consequently, IR detection can be considered as the only practical method of passive detection.

The simplest noncooperative detection system is the visual one using the human eye whether or not it is aided by an optical system. Although the eye apparently is a good "tracker," it is a poor search device because it tires rapidly and is capable of only a slow inefficient search pattern. With the eye (or other visual equipment such as photoelectric detectors), the maximum range is highly dependent on atmospheric conditions. Even in clear daylight, the highlights and shadows on a target may be inadequate for visual detection, for example, when the target appears on the horizon where the contrast is too great for the detection of fine gradations. Better results can be obtained through the use of mechanical, but tireless automatic, detection means such as radar or IR systems.

Since radar equipment uses an electronic detector, it can provide automatic operation and is useful both day and night. One difficulty with radar is that, in addition to the detection set, a noncooperative system must carry a beacon to illuminate the target, and the weight and expense of the equipment rise accordingly. An advantage of an active radar system is that it can provide excellent range data. However, because of the long wavelengths involved in radar, the antenna must be large, and the angular resolution obtained is coarse.

Infrared equipment is similar to visual equipment in that the same optical techniques used for visual telescopes are used to collect the IR energy and concentrate it upon the detector. The electronic and servo equipment that processes the signal from the detector resembles radar equipment in that the same techniques of automatic search and tracking are used. Infrared equipment can "see" exceptionally well through haze but cannot see through clouds. These and other characteristics of noncooperative airborne detection systems are summarized in Table 1.

As aircraft fly higher and faster, longer detection ranges are required. Unfortunately, visual detection ranges can be expected to decrease with increases in altitude. Maximum active radar ranges are a function of target design and aspect and of atmospheric conditions, none offering promise of improvement. Radar ranges can be increased by increasing the beacon power or by increasing the detector sensitivity. However,

Mr. Powell is Assistant Manager and Mr. Kauffman is a Technical Specialist in the Avionics Division.

TABLE 1
Noncooperative Methods of Detection

Characteristics	System: Visual	Radar	Infrared
Beacon	Sun (semi-active)	Required (active)	None required (passive)
Penetration			
Clear air	Good	Good	Good
Haze	Poor	Good	Good
Fog	Useless	Good	Poor
Cloud	Useless	Varies	Useless
Equipment size	Small	Large	Small
Angular resolution	0.1 to 0.33 milliradian	2 to 30 milliradians	0.1 to 1 milliradian
Detection criterion	Area of highlights and shadows	Effective reflecting area	Heat emitted
Range measurement	Poor	Good	Poor
Condition of use	Normal	Automatic	Automatic
Operation against sun	Poor	Fair	Poor
Period of operation	Day only	24 hour	24 hour, night preferred
Power requirement	Small	Large	Small
Maximum unobstructed range	Unlimited	Limited by Beacon power	Unlimited
Search capability	Poor	Good	Good
Tracking capability	Good	Fair	Good

there have been no announcements indicating appreciable improvement in the sensitivity of radar detectors in recent years, and it appears that the major course of improvement lies in increasing the already staggering power outputs of the radar beacon. This would increase range only slightly, by less than the fourth root of the beacon power.

The sensitivities of IR detection systems have been increasing rapidly with the development of new detectors, materials, and techniques. In addition, to obtain the higher speeds, the trend in aircraft equipment has been to provide increasingly greater engine power thereby releasing more and more IR energy. This indicates that, although the achievable detection ranges of IR equipment are very good today, extraordinary increases can be predicted for the future, and more detailed consideration is warranted.

Infrared Radiation Physics

Targets

As shown in Fig. 2, the IR spectrum consists of electromagnetic radiation with wavelengths between 0.7 micron and approximately 1,000 microns. Any solid or liquid object at a temperature above absolute zero emits IR radiation. The spectral characteristics and intensity of the radiation depend on the absolute temperature and the emissivity (blackness) of the emitting surface. Fig. 3 indicates why IR offers the best passive means of detecting aircraft. A target such as an aircraft with a temperature below 800°K. emits little energy in the visible or the radio region but emits considerable infrared energy because it uses a heat engine and is made of metals that emit IR radiation of high intensity. The exhaust gases of an aircraft engine emit energy in a series of spectral "lines" or narrow bands, including water-vapor bands at 1.3, 1.8, and 2.7 microns, and a carbon dioxide band at approximately 4.3 microns.

An observer with "infrared eyes" looking at an aircraft target at night would see a bright glow from all of the hot metal parts and a much fainter emission from the hot exhaust gases. In the daytime, this observer would also see reflections of the sun from objects on the ground and clouds in the background.

Backgrounds

Like a human eye, the passive infrared system sees anything that has sufficient energy to excite it, regardless of the range of the source. The sun behaves much like a blackbody of 6,000°K. temperature, and, although most of its energy is in the visible spectrum (approximately 0.4 to 0.7 microns), it emits considerable infrared energy. Even the reflection of the sun from an object becomes a bright source of infrared energy, and,

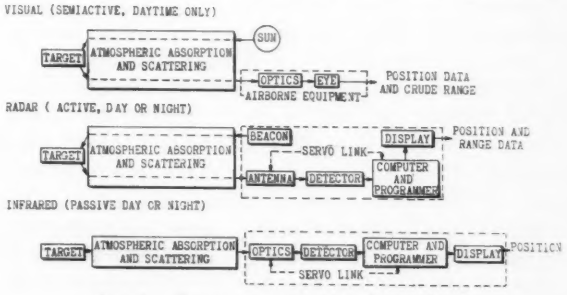


FIG. 1. Noncooperative detection systems.

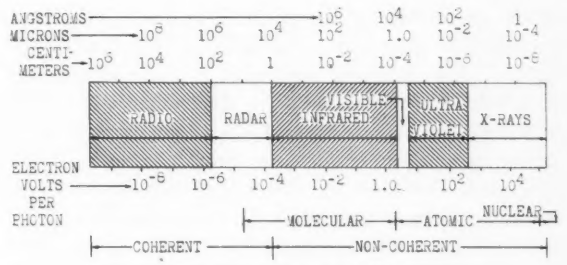


FIG. 2. Electromagnetic radiation spectrum.

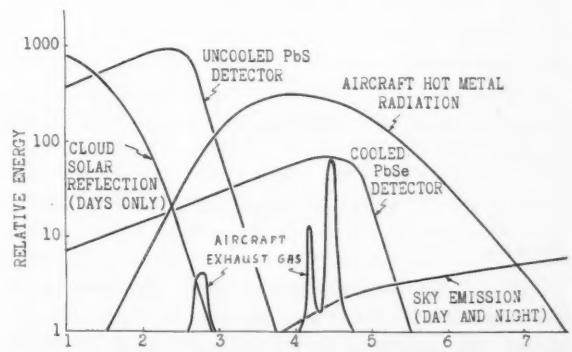


FIG. 3. Infrared spectra.

as implied by the cloud solar reflection curve of Fig. 3, solar reflection from brilliantly illuminated clouds is troublesome for infrared equipment.

The techniques used with active systems—i.e., range gating—to eliminate background objects are not generally applicable. The infrared detection system must differentiate between the target and the background by other means. This is generally done by "color" (or wavelength) filtering and by "space" filtering—i.e., by making the system sensitive only to the strongest detectable wavelength band of the expected target and more sensitive to small high-contrast targets like aircraft than to large diffused targets like clouds.

Atmospheric Transmission

As electromagnetic energy travels through the atmosphere, it is absorbed by the gases and scattered by the particles in the air. At low altitudes, the atmospheric transmission of infrared energy is affected by opaque wavelength regions of absorption and transparent regions of transmission (commonly known as "windows"). The absorption is primarily due to water vapor. Since the water vapor in the atmosphere decreases sharply with an increase in altitude, atmospheric absorption becomes negligible at altitudes greater than 40,000 ft., so that the atmosphere becomes a continuous window, except for extremely long detection ranges. However, even in a vacuum, the energy density of the electromagnetic beam diminishes as the square of the distance from the source, due to the inescapable spreading of the beam. Thus, the maximum range of detection is still limited by the intensity of the source and the sensitivity of the detection system.

The sky in clear weather appears to be blue because of the greater scattering of the blue light (0.4 micron wavelength) than of the red light (0.7 micron) in sunlight. This molecular scattering is the major reason that long-range detection using electromagnetic energy of wavelengths shorter than those of visible light (such as the ultraviolet) is not considered feasible in the atmosphere. Because the infrared energy has a longer wavelength than visible light, it is scattered less. With haze or high cirrus clouds in which the water particles are very small, the scattering of the infrared is much less pronounced than in the visible range. But with clouds or heavy fogs in which the average particle size (approximately 20 microns) is greater than the wavelengths to which current photoconductive IR detectors are sensitive (1 to 7 microns), the scattering of IR energy is almost as complete as the scattering of visible energy.

Infrared Equipment

Detectors

The primary reason for the slow development of effective IR equipment was the lack of a suitable detector. As indicated in Fig. 2, infrared and visible energy is generated by molecular and atomic resonances and is incoherent, whereas radio and radar signals are generated by an oscillator and are coherent—i.e., they are of a single frequency and are in phase so that small quantities of energy can be added to provide a usable receiver signal voltage. The incoherent IR and visible signals are of a continuous band of frequencies and are not in phase, so that any additive detection process gives no signal. Incoherent radiation, however, can be detected by processes in which an electrical characteristic is changed by the absorption of a photon.

One such phenomenon is the photoelectric effect in which an electron bound to an atom is released in a material or from a cathode by the energy obtained from an absorbed photon. Detection is accomplished by collecting and counting the electrons released. A large variety of photoelectric detectors highly sensitive to visible light have been available for some time. Until recently, however, there were no photoelectric *infrared* detectors, owing to the low energy of the infrared photons and the high work functions (quantities of energy required to free the electrons) of the available materials. The development of the semiconductor art since World War II has resulted in a variety of sensitive and fast photoelectric detectors, which, in the infrared region, are mainly of the photoconductive type.

Generally, the achievable sensitivity of photoelectric detectors decreases with increasing wavelength cutoff. As indicated in Fig. 3, uncooled detectors available at present (such as the lead sulfide) are sensitive to radiations only up to about 3 microns in wavelength. Cooling is used on all the photoelectric detectors such as lead selenide (PbSe) that respond to longer wavelengths. Here the thermal energy of the detecting material is so great that, unless the detector is cooled, the resulting self-excited conduction current masks the feeble currents produced by long-wavelength infrared photons.

Relationships between the radiation from aircraft targets and backgrounds and typical infrared detector sensitivities are also illustrated in Fig. 3. The lead sulfide detector is the most sensitive. However, because of spectral-response limitations, it "sees" only a small part of the available energy. Conversely, the less sensitive lead selenide detector "sees" more of the hot-metal radiation and considerably more of the exhaust-gas radiation. The lead sulfide detector responds much more strongly to reflections of sunlight than the longer wavelength detector, particularly if the latter system contains a filter to cut off the energy of short wavelength.

The lead sulfide detector has a slower response, or information output rate, than the long-wavelength detector. On the other hand, in many applications involving mechanical scans, the longer wavelength detector must be used at inconveniently high modulation rates to compete with the lead sulfide detector in sensitivity. Furthermore, although a variety of miniature cryostat systems have been developed to cool detectors, they are costly and often unreliable, particularly for the liquid nitrogen temperatures required to maintain high lead selenide sensitivities.

Optics

The optics of an infrared system can be compared with the receiver antenna of a radar set; however, there are some important differences. For example, inasmuch as the infrared wavelength is about $^{1}/_{1,000}$ of the radar wavelength, much finer resolution can be obtained, and side lobes are insignificant for receiver apertures of practical size.

Typical optical systems used to collect the energy and concentrate it on the detector are illustrated in Fig. 4. They are identical to the systems used in visual telescopes, except that different materials with suitable IR transmission characteristics are used. Among these materials are fused quartz, sapphire, and arsenic trisulfide. Unusual materials currently coming into use include pure germanium, pure crystalline selenium, other semiconductors, and glass-like substances made from various selenium and sulfur compounds. The various materials are combined into complex color corrected optical systems by techniques similar to those used in visual or photographic optics.

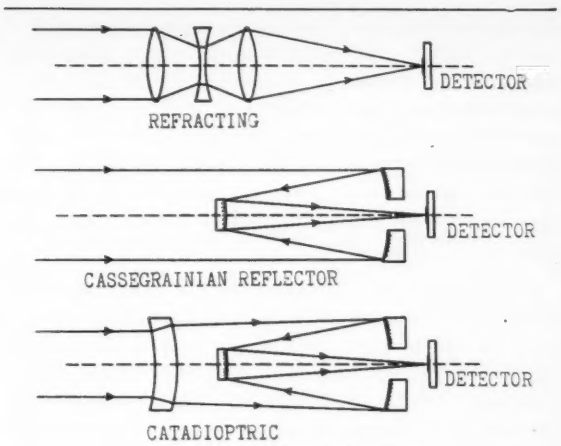


FIG. 4. Infrared optical systems.

Discrimination

As indicated in Fig. 3, background signals exist from both atmospheric and terrestrial emission and reflection. Besides coding the target-position-data signal at the best information frequency for the detector, the information system must discriminate against the background in favor of the target. As mentioned previously, this is done in two ways: first, by color-filtering, accomplished by selecting the wavelength band to which the equipment is sensitive so as to give the most favorable ratio of target signal to background noise; second, by space-filtering, accomplished by making the system more sensitive to a small target of high contrast (like an aircraft) than to a large target of lower contrast (like a cloud), through a rough cross-correlation of the images with a pattern and a reticle.

Electronic System

Whereas the receiving end of the infrared set resembles that of visual equipment, the signal-processing end resembles and is compatible with that of radar equipment. The major differences are that the IR equipment (1) being passive, inherently yields no range data, and (2) being sensitive to much shorter wavelengths, yields a higher order of angular accuracy. Further, being passive, the infrared set is not subject to the ground-clutter or minimum-range limitations of radar equipment.

CONTEMPORARY TECHNIQUES

Search and Track Systems

Passive IR detection equipment for airborne guidance and control can be divided into two primary types, search equipment and track equipment. The search function implies the systematic examination of space for the purpose of locating and identifying a target. The track function implies the continuous observation of a selected target to collect sufficient information to permit predictions to be made about the target (such as an expected future trajectory).

Search systems are designed for the moderately rapid scanning of large sections of the sky. They must be highly sensitive and must be able to "see" several targets in the search field. In order to use the data from a search set, an operator provided with a complex display such as a plan position indicator (PPI) (or equivalent decision-making elements) is required. The more information a search system can provide, in terms of intensity, color, size, etc., the better the decision-making capability.

Track systems, on the other hand, need to survey continuously only a small portion of the sky. Usually, less sensitivity is needed than in a search set since, presumably, the target must have been located with a search system before it was acquired and tracked at closer range. However, a track system must provide highly accurate information on the target position and rate of change of position. Also, by definition, a track set should "see" only one target since presumably the target to be tracked has been selected during the acquisition process. Such target characteristics as intensity, size, and color, which are often important for the search-system display, are unimportant for a tracker display. However, they are extremely useful for facilitating continuous tracking of the proper target, as opposed to secondary or false targets in the background. A good tracker has good discrimination capabilities.

The differences in requirements between search and track equipment usually necessitate differences in internal design. In general, good search equipment gives relatively poor tracking information, and a good track set can usually search only at a very low rate. Because of the size and complexity of radar apparatus, it has ordinarily been necessary to produce airborne equipment capable of performing both functions by changing the mode of operation. This usually results in compromising the performance of the individual functions. However, because of the small size of infra-

red equipment, an installation requiring both the search and the track functions can often afford the luxury of two pieces of specialized equipment. Separate search and track equipment has, of course, the added advantage that a search can be made for additional targets while one target is being tracked.

Infrared Information Techniques

The information processing for IR equipment can be done both between the basic optics and the detector, and between the detector and the final output signal. Eight fundamental types of information-collecting and processing systems have been used in equipment built and tested by Aerojet-General. Four of these can be termed basic, with all possible combinations of these giving four hybrid systems.

Basic Systems

The simple system involves only the elementary optics for defining a field and concentrating the IR energy on a detector. Since most IR detectors have poor static stability, this scheme is useful primarily for detecting rapid changes in IR intensity. The widest application is in cooperative systems for IR communication and modulated-beacon tracking.

The mosaic system is similar, but with the single detector replaced by an array of detectors which use a common lens. For the same field of view, both the information capacity and sensitivity of the mosaic is increased over that of the single detector system. However, the high inherent sensitivities which are theoretically possible are difficult to realize in practice due to the large number of channels required when covering a reasonable field with high resolution. The use of fewer time-shared amplifiers results in a wider band pass with an accompanying reduction in sensitivity. For noncooperative systems in which a point-source target must be distinguished from a background, the use of the basic mosaic scheme alone to provide the required high-resolution "space" filtering is generally impractical.

In the scanning spot system, a small sensitive area is swept through a pattern to cover the entire field of view, as in the early Nipkow mechanical television scan. Although they have been used extensively for search equipment, the success of the spot systems has generally been limited because of difficulty in obtaining good "space" filtering. In order to detect a small IR target against large but lower-intensity backgrounds, the spot size should be kept equal to or smaller than the delivered image of the target, typically of the order of 0.1 milliradian. To stay within the frequency-response capabilities of infrared detectors, the usable search rate with this tiny spot then is unacceptably low for either search or track applications. To compensate, practical systems using the simple scanning-spot technique must employ relatively large spot sizes with a consequent reduction in sensitivity and background discrimination.

Reticle systems utilize a variable-transmission patterned filter in front of the detector upon which the radiation space "seen" by the equipment is imaged. "Space" filtering is accomplished through the use of a fine two-dimensional reticle pattern which transmits exactly 50 per cent of the image-plane energy independent of reticle position Since the signals through the small individual transmission and blocking areas tend to cancel, the reticle when moved or rotated gives no net signal from a uniform background but gives full signal modulation for the essentially point-source targets. Reticle systems alone are usually limited to equipment which covers a solid angle of 20° or less, generally sufficient for trackers and radiometers but small for a search set. Although the detector must subtend the entire field of view, sensitivities comparable to a scanning spot system can readily be obtained by processing the signal to a narrow band pass near the optimum detector frequency.

Hybrid Systems

In the hybrid systems, the particular advantages of the individual basic systems can, to a large extent, be combined through careful design. For example, the hybrid scanning-reticle system differs from the basic scanning-spot system in that the spot is replaced with a reticled detector. This provides the advantage of a large effective sensitive area combined with a fine space patter, desirable for high sensitivity and good background space discrimination. There is great freedom of choice in information processing components and most of the fundamental design requirements for both search and track (or dual mode) equipment can be met, leading to extensive and successful use of scanning-reticle systems.

The hybrid scanning-mosaic system augments the limited search rate capability of the scanning spot system by use of a large number of detectors. This scheme is useful primarily for nocturnal search equipment. Application to daylight operation is more difficult because of the conflicting desire for good "space" discrimination (requiring fine image resolution) over a large rapidly searched field (requiring many detectors with individual electronic channels).

The hybrid reticled mosaic system amounts to a multiple version of the basic reticle system. While the latter is limited primarily to small-field tracker applications, the addition of multiple detectors and associated electronics can provide wide-field equipment suitable for use in day or night search and presence detection. A major advantage over any scanning system, which instantaneously samples only a small portion of the angular field, is that of observing continuously a large volume of space.

The scanning-reticled-mosaic system provides the largest information capacity, useful for search equipment when maximum-search field and maximum sup-

pression of background gradient are required. A common type of this very complex system employs a line array of reticled detectors that optically scan the field of view in a "racetrack" pattern.

Electronic Coding Techniques

An IR information system produces an electrical signal that must contain the required information. The signal may be single channeled or multiple channeled. If a single information channel is used, a single coding of the information may not be sufficient except in special one-dimensional cases. For example, a tracker requires two-dimensional target location information, and good search equipment should provide at least four independent coordinates of information. The types of coding used include continuous coding with amplitude, phase, or frequency modulation; and pulse coding by position, number, width, and height.

In order to provide several coordinates of information over a single electrical channel, either the signal must be multiplexed (time-shared modulation) or more than one type of modulation must be used simultaneously. For example, in tracking equipment, it is common practice for the output to be a sine wave of a signal frequency equal to the scanning frequency. Two simultaneous codings of the information are obtained by modulating the amplitude according to the radius vector, and the phase according to the angle of the vector in polar coordinates. The angular-modulation, pulse-position, and pulse-width types of coding have great advantages for fulfilling the important "go, no-go" requirements of tracking.

Because of the characteristics of the IR detector as a transducer, pulse height and amplitude modulation are used extensively in radiometers and search sets to code intensity information. Pulse-position, pulse-width, and angular (frequency or phase) modulations are often used for the coding of position information since such modulations are produced naturally by the usual optical-information system.

Conclusion

As has been discussed, the spectral regions of visible light, infrared, and radar are applicable in various circumstances for long-range detection of airborne targets. Infrared energy offers the only passive method, is difficult to countermeasure, and is useful both day and night. However, infrared equipment cannot "see" through heavy clouds and does not inherently provide range data. A wide variety of infrared components, techniques, and systems which are suitable for the search and tracking functions required for modern piloted or automatic aircraft control and guidance have been developed in recent years. Such equipment is characterized by low power requirements, small size, and light weight, and is relatively simple and inexpensive. Further exploitation of the comparatively new infrared technology gives promise of appreciable increases in sensitivity and range in the future

IAS Twenty-Seventh Annual Meeting

Hotel Sheraton-Astor, New York City, January 26–29, 1959

The scope of the meeting will be broad to cover the many fields of interest to IAS members. The meetings committee plans to schedule papers on aerodynamics, hypersonics, aeroelasticity, missiles and rockets, missile propulsion, space propulsion, satellites and spacecraft, space medicine, VTOL/STOL aircraft, rotary-wing aircraft, meteorology, etc.

Members or organizations wishing to have papers considered for presentation at this meeting should submit outlines or short abstracts to the Meetings Committee, 2 East 64th St., New York 21, N.Y., no later than August 1, 1958.

Last Call for Roster Listing

All members are reminded that their completed Roster Data Cards must be in by May 30 if they wish to change their listing in the next edition of the Roster. Members whose names do not appear in the 1957–1958 Roster are especially urged to return their cards immediately.

Those members not returning the data cards will be listed by repeating the entry that appeared for them in last year's Roster. This is your last opportunity to be correctly listed in the 1958–1959 IAS Roster.

XUM

The various steps involved in an actual pressure controller system design and the method of selection of system elements based upon electronic, hydraulic, thermodynamic, and other processes are discussed.

Rocket Test Stand Pressure Controller Design

Gordon E. Click and Robert G. Halliday
Kelsey-Hayes Company

A TYPICAL HIGH-PERFORMANCE pressure control system is shown in Fig. 1. This system involves the use of pressurized helium or nitrogen as an upstream pressure source for controlling the flow of liquid oxidizers and fuels, say to rocket thrust chambers which are under test.

The basic components of the pressure control system include: a pressure reducing valve which is to be controlled such that the pressure over the fuel or oxidizer is constant during the changes in both supply pressure and load requirements; a pressure sensing device for generating a signal in proportion to the actual pressure; a controller for modification of the pressure signal as is usually required in a high-performance system; and a positional servosystem which adjusts the pressure reducing valve as commanded by the controller.

A considerable amount of analysis is necessary in order to properly represent the mathematical model of the overall system. The fluid flow equations, for example, are very complex as well as nonlinear primarily because a gaseous compressible medium is involved as the driving source. After simplification of the nonlinear equations, the resulting mathematical model must be examined to establish the functional requirements of the basic system building blocks such that the static and dynamic behavior of the overall system will be within the tolerances allowed in the system specifications. The final step is the conversion of the functional requirements into component selection and/or design and fabrication. It is the purpose of the following to illustrate these various necessary steps in the development of a pressure control system.

ANALYSIS

The following analysis mathematically identifies the system (Fig. 1) to be controlled by considering the flow characteristics of the pressure reducing valve, the thermodynamic condition of state of the inert pressurizing gas, and the magnitude of the operating point of liquid propellant flow (from the base of the pressurized tank). Following this, the dynamics of the reducing valve positioning servo and the possible dynamics of the controller are considered.

The equations describing the characteristics of the various portions of the system are quite nonlinear. Such equations do not lend themselves to the analytical considerations of system dynamics; machine methods, although capable of solving the nonlinear equations, converge on a proper solution only after the application of considerable "hunt & peck" techniques. The latter procedure is not initially desirable since it fails to provide a sound basis of understanding of the dynamics of the system. To simplify the problem of analyzing the dynamic behavior of a system characterized by many nonlinear equations, each of the equations developed will be linearized about assumed operating points. All of the system variables will be viewed as total quantities comprised of the sum of steady-state or operating point values and perturbation quantities. Throughout the analysis the total quantities will be designated by capital letters, the operating point values (constants) by "zero" subscripts, and the perturbation quantities by lower case letters. To insure satisfactory performance at all operating points, the dynamic be-

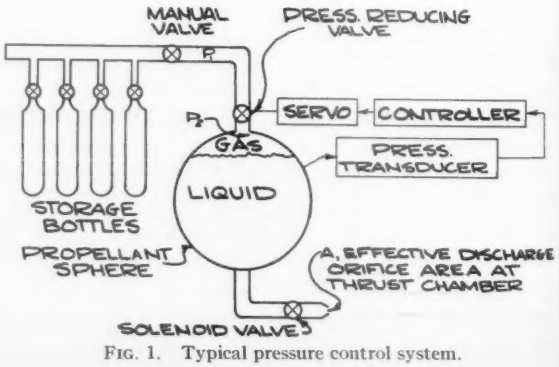


FIG. 1. Typical pressure control system.

The authors are Staff Engineers in the Control Specialists Division.

havior must be checked at several intermediate points representing extremes of the several variables involved.

Weight Flow

The weight rate of flow of the compressible fluid (inert gas) through the pressure reducing valve for the non-critical (subsonic) flow condition can be shown to be of the form

$$W = KX_v\sqrt{P_2(P_1 - P_2)} \qquad (1)$$

where

W = weight rate of flow (lb./sec.)
X_v = pressure reducing valve displacement (in.)
P_1 = upstream inert gas storage or supply pressure (psia)
P_2 = desired downstream inert gas pressure (psia)
K = lumped proportionality constant, including weight density of flowing fluid, ratio of valve opening to maximum displacement, adiabatic gas constant effect, etc. (in./sec.)

For critical flow, $P_2 \leqslant P_1/2$ the weight rate of flow is independent of P_2 and Eq. (1) reduces to $W = KX_vP_1/2$.

Eq. (1) is nonlinear in that both products and exponents are present; the weight rate of flow, however, is a function of three variables—i.e.,

$$W = W(X_v, P_2, P_1) \qquad (2)$$

and the first order Taylor's series expansion of the perturbed flow reduces to

$$w = (\partial W/\partial X_v)x_v + (\partial W/\partial P_2)p_2 + (\partial W/\partial P_1)p_1 \qquad (3)$$

The term p_1 in Eq. (3) represents a perturbation of the supply pressure which may be neglected since the decay of the storage pressure P_1 is extremely slow compared to the time variations (and hence magnitudes) of the perturbed quantities w, x_v, and p_2. Thus

$$w = W_x x_v - W_p p_2 \qquad (4)$$

where

w = a small change in the weight rate of flow (lb./sec.)
$W_x = (\partial W/\partial X)_0$ = the slope of the curve of weight flow through the pressure reducing valve vs. the valve displacement at given operating point W_0
$W_p = -(\partial W/\partial P_2)_0$ = the slope of the curves of weight flow through the valve vs. desired downstream pressure at the given operating point W_0

A second weight rate of flow expression is available from the characteristic equation of a gas:

$$P_2V_2 = N_2RT_2 \qquad (5)$$

where

V_2 = the volume of inert gas maintained at the desired pressure (cu.in.)
N_2 = the weight of inert gas maintained (lb.)
T_2 = the temperature of the inert gas maintained (°R.)
R = the gas constant (in./°R.)

Eq. (5) may be differentiated with respect to time to obtain

$$P_2(dV_2/dt) + V_2(dP_2/dt) = RT_2(dN_2/dt) + RN_2(dT_2/dt) \qquad (6)$$

Runs of short duration do not materially decrease the initial temperature of the gas; therefore, the derivative (dT_2/dt) is assumed negligible. Noting that the quantity (dN_2/dt) is identical to W of Eq. (1), Eq. (6) may be written

$$W = (1/RT_2)[P_2(dV_2/dt) + V_2(dP_2/dt)] \qquad (7)$$

Substituting the sum of steady-state operating values and the corresponding perturbations of the variables in the above and eliminating the products of perturbation quantities, the perturbed weight rate of flow expression becomes

$$w = \frac{1}{RT_{2_0}}\left[P_{2_0}\frac{dv_2}{dt} + p_2\left(\frac{dV_2}{dt}\right)_0 + V_{2_0}\frac{dp_2}{dt}\right] \qquad (8)$$

Liquid Propellant Flow Rate

An additional expression, necessary to describe the system process, must relate the liquid propellant exhaust flow to the gaseous flow expressions previously derived. The propellant flow may be expressed:

$$Q = (dV_2/dt) = CA\sqrt{(2/\rho)(P_2 - P_3)} = K_QA\sqrt{P_2} \qquad (9)$$

where

Q = volumetric flow rate (in.^{3}/sec.)
C = effective orifice coefficient
A = exhaust orifice effective area (in.^{2})
ρ = mass density of fluid (lb. sec./in.^{4})
P_2 = upstream fluid pressure (psi)
P_3 = exhaust pressure (assumed zero)
$K_Q \equiv C\sqrt{2/\rho}$ = lumped constant (in.^{2}/lb.$^{1/2}$ sec.)

Fluid compressibility is not considered here since its effect would be overshadowed by the dominant dynamical contribution of the highly compressible gas pressure source. Fluid inertia and viscosity are also disregarded for similar reasons.

Eq. (9) may be linearized to form

$$q = C_a a + C_p p_2 \qquad (10)$$

where

$$C_a = (\partial Q/\partial A)_0 \quad \text{(in./sec.)}$$

$$C_p = (\partial Q/\partial P_2)_0 \quad \text{(in.}^5\text{/lb. sec.)}$$

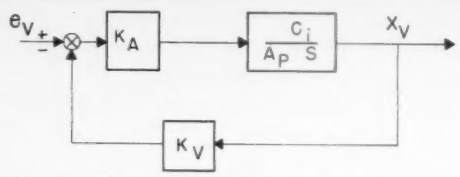


FIG. 2. Block diagram, electrohydraulic actuator.

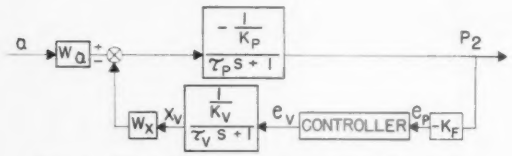


FIG. 3. Block diagram, pressure controller system.

and combined with Eqs. (4) and (8) to result in a single expression relating the pressure to be controlled, the valve displacement which provides the means of controlling the pressure, and the fluid exhaust orifice area which provides the "load":

$$\left(\frac{P_{2_0}C_a}{RT_{2_0}}\right)a - W_x x_v = -p_2\left\{W_p + \frac{P_{2_0}C_p}{RT_{2_0}} + \frac{[(dV_2/dt)]_0}{RT_{2_0}}\right\} - \frac{dp_2}{dt}\frac{V_{2_0}}{RT_{2_0}} \quad (11)$$

Eq. (11) may be placed in a more readily recognized form by substituting new constants for the several terms and by performing the LaPlace transformation:

$$p_2 = [-(1/K_p)/(\tau_p s + 1)]\cdot(W_a a - W_x x_v) \quad (12)$$

where

$$W_a \equiv P_{2_0}C_a/RT_{2_0} \quad \text{(lb./in.}^2\text{ sec.)}$$

$$K_p \equiv \left[W_p + \frac{P_{2_0}C_p}{RT_{2_0}} + \frac{[(dV_{2_0}/dt)]_0}{RT_{2_0}}\right] \quad \text{(in.}^2\text{/sec.)}$$

$$\tau_p \equiv K_\tau/K_p \quad \text{(sec.)}$$

$$K_\tau \equiv V_{2_0}/RT_{2_0} \quad \text{(in.}^2\text{)}$$

Valve Servodynamics

Evaluation of the time constant τ_p for many high-performance systems reveals the need for a pressure reducing valve servosystem having a relatively high velocity and having a capability of exerting appreciable forces simultaneously. Such circumstances eliminate from any consideration the application of conventional air or electric motor driven valves. Electrohydraulically powered valves are the only means presently available for meeting the usual requirements. A satisfactory mathematical expression for the dynamics of an electrohydraulic actuator system (Fig. 2) in this application is:

$$x_v = (1/K_v)[1/(\tau_v s + 1)]e_v \quad (13)$$

where

x_v = output displacement (in.)
e_v = input voltage (volts)
K_v = feedback potentiometer gain (volts/in.)
τ_v = $A_p/K_A K_v C_i$ (sec.)
A_p = effective actuator piston area (in.^{2})
K_A = amplifier voltage to current gain (ma/volt)
C_i = electrohydraulic valve gain (in.^{3}/sec. ma)

Eq. (13) neglects the effect of actuator load variation (with controlled valve displacement), oil compressibility, and load inertia since experience has shown that these effects are negligible in systems of the type under consideration.

If a pressure-to-voltage transducer is provided with the characteristics

$$e_p = -K_F p_2 \quad (14)$$

where

e_p = output voltage of transducer
p_2 = controlled pressure (psi)
K_F = transducer gain (volts/psi)

a basic pressure controlled system could be represented by the block diagram of Fig. 3. The block labeled "Controller" is, as yet, unidentified and will supply the overall system with whatever gain or dynamic characteristic is dictated by the remainder of the system.

System Component Specification

To this point, consideration has been given only to the development of the equations which might be common to all pressure control systems. The application of these equations to a system design will now be outlined.

In the block diagram of Fig. 3 the blocks W_x and W_p are determined by the choice of the pressure reducing valve. These valve characteristics are dictated by the maximum desired flow rate of pressurizing gas and the minimum pressure drop across the valve which will result in this flow. The valve may, therefore, be considered part of the "fixed" system to be controlled. The elements of the overall system available to the designer for exercising control of the pressure p_2 are the feedback transducer K_F, the Controller, and the hydraulic servoactuator.

Electrohydraulic Servo

The area of the piston used to drive the pressure reducing valve is based upon the maximum expected unbalanced load reflected by the stem in the pressure reducing valve and the hydraulic oil pressure available for the actuator. With the area so fixed, the next specification sets the maximum velocity which will be required of the servopiston, for it is this information which dictates the maximum flow required of the electrohydraulic transfer valve which meters the hydraulic fluid to the piston (methods of establishing the velocity limit are discussed later). In general, the time constant (τ_v) of the hydraulic servo is chosen to be quite small compared to the time constant of the process (τ_p

in this case) to achieve fast response without undesirable oscillations. The number of milliamperes in the transfer valve to achieve full flow, the gain of the amplifier driving this valve, and the gain of the piston position feedback potentiometer combine with the above piston area to establish the "time constant." The distribution of these gains between the transfer valve, the amplifier, and the feedback potentiometer is best established when the other parts of the control elements have their functional requirements outlined.

Pressure Transducer

The pressure transducer is the device which converts a pressure to a proportional signal for use in the remaining controlling elements. In some applications the pressure transducer measures the total pressure to be controlled. The signal generated by it is compared with a "set-in" or command signal, and the difference is utilized by the remaining controlling elements to reduce the difference to acceptable values. In other applications the pressure transducer measures the difference between the pressure to be controlled and a reference pressure held in a small pressure vessel. The choice of method and transducer requires consideration of transducer response time, hysteresis for both large and small variations of pressure, pressure overload range without damage, electrical characteristics, and stability of characteristics with environmental changes.

The response time must be quite small compared to the servo and pressure time constants to avoid the possible instability problems associated with achieving high performance. Conventional passive transducers designed for high-pressure operation (using diaphragms instead of bellows) have time constants which are often negligible when compared with the remainder of the system. Some active (force balance) types of pressure transducers have very finite time constants and may not be suitable in many systems.

The hysteresis of the transducer has considerable bearing on the performance of the overall system in that the system may easily oscillate through a pressure range of two or three times the pressure hysteresis range. Manufacturers of pressure transducers usually quote linearity and hysteresis as a percentage of the total range because their devices are most often connected to pressure indicators. Such information is of little value to the controlling system designer interested in high performance with stability since the control systems operate about a certain commanded point. The hysteresis as a percentage of pressure deviation amplitude is the type of information having meaning to the control system designer. The hysteresis in transducers, due primarily to sliding friction, usually remains near the given percentage of maximum range. Whereas the hysteresis in other transducers, not due to sliding friction, is much closer to being a constant percentage of the pressure variation.

Pressure control systems of the type under consideration operate to reduce a higher pressure source to a desired pressure. If certain components of the pressure installation fail to perform as desired, it is possible to impress full source pressure on the pressure transducer with possible damage resulting (particularly if the transducer is of the differential type). Overpressure safety devices can be employed to reduce this hazard, but, if the safety devices have to be set very close to the pressure being controlled, it is possible to initiate large amplitude oscillations caused by dynamic coupling between the safety devices and the pressure controlling system. Many manufacturers now guarantee their specifications as valid following 100 per cent pressure overload.

The nature of the electrical output signal dictates the character of the controlling elements connecting the pressure transducer to the servoactuator. The four most common devices for conversion of a bellows or diaphragm deflection to an electrical quantity are the strain gage, the potentiometer, the "E" transformer, and the variable reluctance type. The first two are frequently used in d.c. systems while the latter two are used only in a.c. systems. The strain-gage type is desirable from the accuracy, response time, and sliding friction points of view but does suffer from relatively low output. The potentiometer, on the other hand, has a relatively high output, but the hysteresis as a percentage of a small deviation is usually quite high. The a.c.-type units usually have higher outputs than do strain-gage types, but a source of high frequency voltage is needed to excite them. The choice of transducer output must take into consideration the type of power available, the type of controllers available, and, of course, the dynamic requirements dictated by the overall dynamic system requirements.

When attempting to control a pressure at a given point in a system, it is important that the transducer measure the pressure statically and dynamically. Transducers are therefore frequently mounted directly at the point to be controlled to avoid the time delays which could exist in piping the pressure signals to a remotely located transducer. In such locations, they are frequently subjected to severe vibration, temperature, and humidity variations. Assurance should be gained that the transducer will stay within the required performance specifications over the complete range of expected environmental conditions.

General Controller

The controller is the remaining item needed to make a complete pressure control system. It may be a simple proportional-only controller in which the electrical signals generated by the pressure transducer are merely amplified or attenuated before being sent to the servoactuator; or it may be relatively complex with provisions for integration, proportion, and rate, as well as a host of other provisions which are found to be necessary or desirable for some particular installation.

The relative complexity of the controller is best established by dynamic analysis of the remaining por-

tions of the control elements combined with the system to be controlled.

Single-Mode Controller

If the controller is initially assumed to pass the pressure signal without modifications,* the transfer function relating the controlled pressure p_2 to the downstream liquid valve area, a, can be written in the form

$$\frac{p_2}{a}(s) = \frac{-(W_a/K_\tau)[s + (1/\tau_v)]}{s^2 + 2\zeta\omega_n s + \omega_n{}^2} \quad (15)$$

where $2\zeta\omega_n = [(\tau_p + \tau_v)/\tau_p\tau_v]$

$$\omega_n{}^2 = (1/\tau_p\tau_v)[1 + (W_x K_F/K_p K_v)]$$

The majority of systems require that there be no tendency for oscillatory behavior following a disturbance. Consequently, if the damping term, ζ, in the characteristic equation of Eq. (15) is set to unity, the transfer function may be simplified to the form

$$(p_2/a)(s) = -(W_a/K_\tau)\{[s + (1/\tau_v)]/(s + \omega_n)^2\} \quad (16)$$

The steady-state gain (letting $s = j\omega = 0$) is seen to be equal to $W_a/K_\tau\tau_v\omega_n{}^2$. This gain represents the droop in pressure from the desired pressure level for each unit of liquid valve orifice area after all transients have subsided. The entire transient variation in pressure following a sudden change in "load" is given by the inverse transformation of Eq. (16), or

$$p_2(t) = -\frac{A_0 W_a}{K_\tau}\left\{\frac{1}{\tau_t\omega_n{}^2} + \left[\left(\frac{\tau_v\omega_n - 1}{\tau_v\omega_n}\right)t - \frac{1}{\tau_v\omega_n{}^2}\right]e^{-\omega_n t}\right\} \quad (17)$$

The transfer function relating the control valve displacement and the load is

$$(x_v/a)(s) = (K_F W_x/K_p K_v \tau_p \tau_v)\cdot[1/(s + \omega_n)^2] \quad (18)$$

and the valve transient response to a sudden change in load A_0 is

$$x_v(t) = \frac{A_0 K_F W_x}{K_p K_v \tau_p \tau_v}\left[\frac{1 - (1 + \omega_n t)e^{-\omega_n t}}{\omega_n{}^2}\right] \quad (19)$$

The magnitude of load change which can be tolerated without deteriorating the performance dynamically due to servo positional or velocity saturation is obtained from Eq. (19) and its derivative respectively. If normal variations in load are found to cause the servo to velocity saturate appreciably, the simplest method of establishing the effects is through the use of the analog computer. This is particularly true when attempting to consider the nonlinearities in the system controlled by the more complex type of controller.

Three-Mode Controller

If the pressure droop of Eq. (17) is excessive or if the transient response indicates that the pressure does not reach the minimum level in a sufficiently short time, more complex techniques need to be applied. The droop could be greatly reduced if the gas valve position versus the fluid valve position for zero droop were known at all the desired pressure levels. Then the pressure control system would have only to take care of the residual errors. However, the complexity of the equipment needed to program this would greatly exceed that of other available techniques. A theoretically more desirable technique involves the increase in proportional gain (to reduce the droop) and the utilization of rate feedback to dampen the oscillatory system created by increasing the proportional gain. The rate scheme, however, has a fundamental drawback in systems that show velocity saturation of the servos in that, if a sudden disturbance should cause velocity saturation, the rate signal would become ineffective through the servo, and the system would operate as if the higher proportional gain existed alone. Faster servos could be applied to the system, but the costs become prohibitive before appreciable improvement in performance is realized. The single scheme which permits (theoretically) the elimination of droop without effecting the stability or without adding complex and expensive equipment is integration. Integration circuits can provide very high steady-state gains to practically eliminate all measurable droop without increasing the gain at the frequencies which the overall system would tend to oscillate with proportional gain increase alone. A small amount of rate may then be applied to increase the stability of the system for relatively small perturbations in pressure without creating a poorly damped or unstable oscillation if a disturbance should cause saturation of the servo.

There are two generally acceptable methods of determining the proper amount of integral, proportional, and rate gains in a three-mode controller. One scheme involves "tuning" the system plus controller by disturbing the system and adjusting first the proportion, then the integral, and finally, the rate gains until the disturbances demonstrate satisfactory performance. If the cost of running the system is not excessive, an experienced person can tune a system at a relatively small cost. High-pressure control systems, however, are often limited to operations of relatively short time intervals, and the cost of running can easily exceed the cost of adjusting the gains by other means.

The transfer function of a practical controller generating the sum of integral, proportion, and rate is

$$\frac{e_v}{e_p}(s) = \frac{\tau_1\tau_2 K_c}{\tau_3}\cdot\frac{[s + (1/\tau_1)][s + (1/\tau_2)]}{s[s + (1/\tau_3)]} \quad (20)$$

The terms K_c, τ_1, and τ_2 result from the combination of the three modes. The term $1/\tau_3$ is usually added in quality equipment to reduce the noise and response of the overall system at frequencies higher than the band of interest. The term K_c is the controller gain and may be considered to include the pressure transducer gain K_F.

* Unity gain and zero dynamics in the "Controller" block of Fig. 3.

Fig. 4 contains the Bode diagrams of the *open-loop* transfer function x_v/a (considering the servo as disconnected from the valve) without rate or integration (dotted lines) and with rate and integration (solid lines). At low frequencies (corresponding to slowly changing loads) the controller is seen to provide more gain than the proportional-only type of controller while at the mid-frequencies between $1/\tau_v$ and $1/\tau_p$ the gain is seen to be quite close to that of the simple controller. At the high frequencies, the gain is caused to increase again between the frequencies $1/\tau_2$ and $1/\tau_3$. The low frequency gain is adjustable by controlling the position of $1/\tau_1$ (integration control) while the high frequency gain between $1/\tau_2$ and $1/\tau_3$ is established by controlling the position of $1/\tau_2$ (the rate control). The term $1/\tau_3$ is usually added a decade or so above $1/\tau_2$ to prevent interference with the rate action.

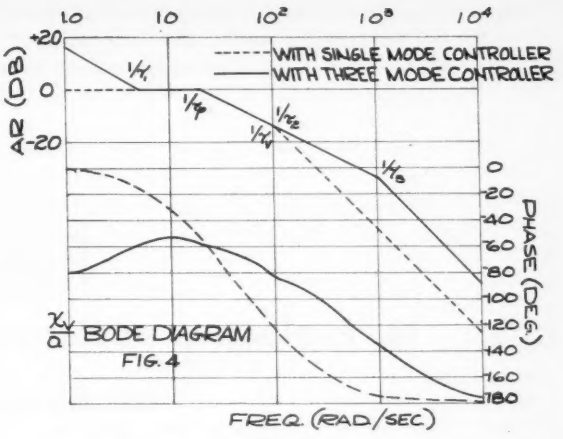


FIG. 4.

CONCLUDING REMARKS

Certain basic criteria have been presented in the foregoing analysis. These criteria, although not necessarily applicable to all pressure control loops, have proved valuable as guides in the design of systems similar to the one described. Modification of the techniques employed will be dictated by the severity of the operating conditions, the complexity of the system, and the degree of control optimization required.

The method of approach to this and similar problems has been the prime intent of this paper. Analytical techniques have been emphasized, but it should not be construed that analog computer solutions can be disregarded. The analytical methods usually provide orders of magnitude only of the system parameters which may be adjusted; critical design factors are also indicated by "hand" methods—i.e., regions requiring closer scrutiny. The final optimization should be obtained from analog computer transient data whenever possible with the dominant discontinuous type nonlinearities (hysteresis, velocity saturation, position saturation, etc.) of the system included in the computer setup.

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The increasingly severe vibration environments encountered in high-performance aircraft and missiles, together with more stringent reliability requirements, have focused attention on the relatively new field of random vibration testing.

Random Vibration Testing

for Evaluation of Electronic Components for Aircraft and Missile Environments

James P. Monroe
Lear, Incorporated

INCREASINGLY SEVERE VIBRATION environments in high-performance aircraft and missiles, together with more stringent reliability requirements, have focused increasing attention on the relatively new field of random vibration testing. Conclusive test results depend on empirically matching, through proper equalization procedures, the random vibration equipment to the component under test and the prescribed environmental specification.

Sinusoidal testing, of course, simply requires mounting a test item on the exciter and turning up the vibration. Such a procedure in random vibration testing, however, will not reveal either the characteristics of the vibration test or the extent to which the item has been tested at the frequencies to which it is most sensitive. Variations in vibration immunity are especially true of electromechanical devices and electronics packages which contain such sensitive components as relays and vacuum tubes. It is quite possible that an item subjected to an unknown random test might fail at 1 *G* r.m.s. but pass a known and controlled random test of 10 *G* r.m.s. It is evident, then, that the total r.m.s. *G* random vibration level does not provide a reliable standard for the test. Since random vibration is composed of many component frequencies of randomly varying amplitude and phase, it cannot be described as the level of the sum of all these components; it must be described by the contribution of each component in forming the total level.

CHARACTERISTICS OF RANDOM VIBRATION

It can be shown mathematically that any random motion may be described by a series of sinusoidal components, each occurring at its own frequency and amplitude. Since the amplitude of each component is not constant but has a normal or Gaussian distribution of instantaneous accelerations, it is convenient to express the level of the component in terms of its root-mean-square value. The Gaussian distribution means that the probability of occurrence of instantaneous accelerations is such that the acceleration will be less than the r.m.s. level 68 per cent of the time, less than twice the

Mr. Monroe is Head, Vibration Test Facility, at the Grand Rapids Division.

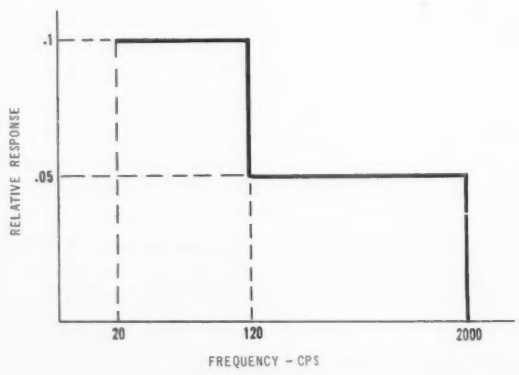

FIG. 1. Power spectral density.

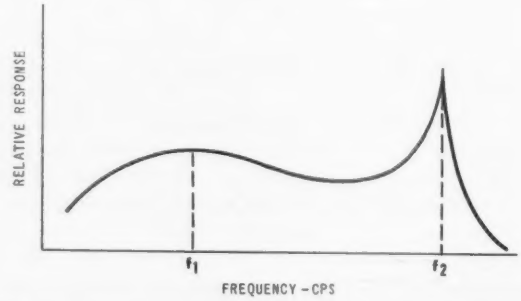

FIG. 2. Typical response curve—random vibration system.

r.m.s. level 95 per cent of the time, and less than three times the r.m.s. level for 99.7 per cent of the time.

Describing the random motion in terms of its components leads to a property of vibratory motion called the "acceleration density" which, when plotted as a function of frequency, gives a more precise picture of random motion. The equation for acceleration density is

$$G = \underset{B \to 0}{\text{Limit}} \, (a^2/B)$$

where a is the root-mean-square of the random acceleration, B is the bandwidth or range of frequencies under consideration, and G is the acceleration density in units of g^2/cps. If the bandwidth, B, is made to approach zero cps, the acceleration density given by the equation is that of a single component frequency. A plot of the acceleration density of each component frequency gives a g^2/cps versus frequency curve for the frequency spectrum of interest and is known as the "Power Spectral Density" curve. It is apparent that a complete description of a random vibration test requires a specification of the power spectral density (PSD) to be used. When the PSD is flat (that is, all frequency components are present at equal level), the random motion is referred to as "white noise."

The total r.m.s. vibration level represented by a particular PSD may be determined by the equation

$$G \text{ r.m.s.} = \sqrt{\sum_{f_1}^{f_2} (g^2/\text{cps})(\Delta f)}$$

where g^2/cps is the acceleration density of each frequency component, f_1 and f_2 are lower and upper *limits* of the frequency spectrum under consideration, and G r.m.s. is the total r.m.s. level of the random vibration. This equation simply states that the total r.m.s. acceleration is equal to the square root of the area under the power spectral density curve. The total r.m.s. acceleration indicated by the PSD of Fig. 1 is

$$G \text{ r.m.s.} = \sqrt{[0.1 \; g^2/\text{cps} \times (120 - 20) \text{ cps}] + [0.05 \; g^2\text{cps} \times (2000 - 120) \text{ cps}]}$$

$$G \text{ r.m.s.} = \sqrt{10g^2 + 94g^2} = 10.2$$

Characteristics of a Random Vibration System

The response characteristic of a random vibration system is not flat but is shaped as in Fig. 2. Frequencies f_1 and f_2 are the electrical and mechanical resonances of the vibration exciter and will change as the mass load on the exciter is changed. If a white noise spectrum or any other particular PSD is desired in a test, the system transfer characteristic must be shaped or "equalized" to produce the desired PSD from a white noise input voltage. The mass-loading effect of the test item on the exciter is not the only consideration in equalizing the system for a test. The effect of a large test item and fixture with several resonances must also be considered (see Fig. 3). If one or more of the large peaks coincides with critical frequencies in an electronics package, the item will be very seriously overtested. Experimental investigation indicates that if the component were tested on the basis of an unequalized PSD such as in Fig. 3 and assumed to have been tested by white noise, it might have been overtested by a factor as large as 20 to 1 at some frequencies.

In order to perform a random vibration test of known characteristics, the test item (or a facsimile) and its fixture must be mounted on the exciter and the shape of the unequalized PSD determined. The transfer characteristic of the system is then shaped by equalizing equipment to give the desired response as indicated by the PSD in the test specification. This equalization procedure requires several hours for each direction in which the test item is to be vibrated. The time required for setup, of course, means that a last-minute request for a new random vibration test cannot be filled

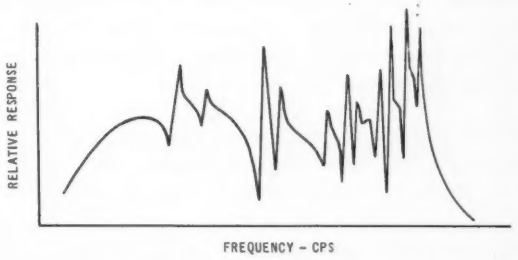

FIG. 3. Typical response of a random vibration system when driving a resonant load.

FIG. 4. Personnel conduct a vibration test of an inertial guidance component at the Vibration Laboratory of Lear's Grand Rapids facility.

with a test of known characteristics. If an unequalized test is conducted, nothing is revealed except the total r.m.s. acceleration level, and any evidence of vibration immunity in the test item cannot be conclusive.

A "standard" equalization may be established for use with small test items having resonances which are not too severe. This standard equalization may be used in cases where the "mass-resonance" product is small, compared with the mass of the exciter moving element. If this relationship exists, the effect of the resonating mass on the PSD is small and may be ignored. "Mass-resonance" product is defined as the mass of the resonating element, multiplied by the ratio of the unit vibration to the input excitation at the resonant frequency. A mass-resonance product equal to one-third the weight of the moving element will produce a deviation of the level of the PSD at the resonant frequency of about 10 per cent.

Standard practical limits must be set up when designing random vibration test equipment; hence the unlimited peak amplitudes of a true Gaussian distribution cannot be realized. The accepted standard for random vibration systems is a capacity to produce peak accelerations equal to three times the rated r.m.s. output. This means that 99.7 per cent of a true Gaussian distribution may be realized. Assuming a system with a maximum r.m.s. output force of 2,500 lbs. and a moving element weight of 72 lbs., the maximum (empty table) output acceleration is 34.7 G r.m.s. The maximum output acceleration obtainable with a load on the table is

$$G \text{ r.m.s.} = 2{,}500 \text{ lbs.}/(72 \text{ lbs.} + X)$$

where the 2,500 lbs. is the rated r.m.s. output force of the exciter, the 72 lbs. is the weight of the exciter armature, and X is the weight of the test item and fixture. Assuming a white noise spectrum, the maximum acceleration density obtainable is

$$g^2/\text{cps} = G^2 \text{ r.m.s.}/B$$

G r.m.s. is the maximum r.m.s. output acceleration and B is the bandwidth of the desired frequency spectrum.

Let us suppose that an item with fixture of total weight equal to 28 lbs. is to be tested. The frequency spectrum covers a range of 20 to 2,000 cps. What is the maximum white noise acceleration density that can be used? The maximum r.m.s. acceleration is equal to the r.m.s. rated output force (2,500 lbs.) divided by the total weight, armature plus test item, to be vibrated (100 lbs.) and is 25 G r.m.s. The maximum white noise acceleration density equals the square of the maximum r.m.s. acceleration (25 G r.m.s.) divided by the bandwidth (1,980 cps). The maximum white noise acceleration density to which the item may be tested is then 0.316 g^2/cps. Since the maximum acceleration density is inversely proportional to bandwidth, it is possible to obtain a larger g^2/cps level by reducing the bandwidth and running the test in two or three parts to cover the total desired spectrum.

All questions and points of interest pertaining to such a specialized field of investigation as random vibration testing cannot, of course, be covered in the space available. An increased appreciation for the necessity of proper testing techniques, however, may be realized from an increased familiarity with the complexity of random motion.

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Inertial Navigation Systems *(Continued from page 65)*

For the longitudinal-vertical channel coupling it is found that:

(1) The coupling tends to reduce the error for short flight times although a divergence of range error exists eventually which is similar to that which would be found in the "uncoupled" treatment.

(2) Some method of obtaining vertical velocity, as well as radius information, is desirable in order to limit the radius error and therefore the range error for flight durations where the divergence rate becomes critical. This time for divergence varies from one-half hour to one hour for the cases considered here.

For more general cases where a hypersonic flight involves long-time steady accelerations (or decelerations), expressions similar to those of the constant velocity example result, and an extra term proportional to forward acceleration appears in the error responses.

In conclusion it appears that inertial navigation systems for hypersonic aircraft can be analyzed relatively simply in spite of the coupling effects which must be considered.

A description of the Model 120 automatic navigation and flight control system.

Advanced Doppler Navigation for the U.S. Army

J. R. Iverson
Ryan Aeronautical Company

SELF-CONTAINED Doppler-type airborne navigation equipment has rapidly assumed a prominent role in military and civilian aviation. The increased complexities of modern aircraft operations have demonstrated the inadequacies of existent navigation techniques; particularly from a military standpoint, current techniques suffer severe limitations. For example, celestial navigation requires good visibility and time-consuming calculations; radio aids require extensive ground stations which are not secure during wartime; radar map matching has obvious limitations over the sea and other areas void of prominent radar characteristics; and traditional dead reckoning utilizing true air speed and wind estimates is subject to large errors.

The advent of self-contained Doppler ground-speed sensors has made accurate dead-reckoning navigation a reality. Dead reckoning is a navigation technique based on computing the present position by continuous integration of aircraft velocity from the last position fix. The accuracy of this method has previously been limited because of inaccuracy of ground-velocity data. Present position is necessary to determine other important navigation information such as course and distance-to-destination. These computations, made automatically, continuously, and accurately, reduce the navigation problem to a simple reading of indicators thereby relieving the pilot and crew for other functions. Doppler systems find application in a variety of jet- and propeller-driven aircraft, helicopters, airships, and some missile types.

The Model 120 automatic navigation and flight control system for U.S. Army fixed and rotary-wing aircraft is described in this paper.

Design Features

Security classification has recently been removed from Doppler systems and the many diverse approaches followed by Doppler equipment developers have been revealed. The Ryan Aeronautical Company, Electronics Division, has developed a family of advanced lightweight ground-velocity indicators and navigators which are simple, reliable, and available. The Model 120, an advanced integrated navigation and flight instrumentation system for U.S. Army aircraft, is characterized by the following major design features:

(1) Continuous-wave transmission is used since it permits the most reliable, the simplest, the most lightweight, and accurate system. Additionally, it is inherently suited to operation at the very low altitudes encountered in "nap of the earth" operations as well as altitudes in excess of 70,000 ft.

(2) The antenna system is rigidly fixed to the aircraft and data stabilization is used. The advantages over a mechanically stabilized antenna system are: higher reliability, lower installed weight, smaller aircraft cutout area, lower volume, lower power consumption, ease of calibration, and greater attitude coverage.

(3) A two-beam antenna system is used for normal navigation since this allows the most lightweight and smallest system. Additional radar beams are employed in rotary-wing applications where vertical speed indications and hovering capabilities are required.

(4) A direct-to-audio detection system is used on the basis of extensive practical experience to achieve reliability, simplicity, minimum practical weight, and maximum practical sensitivity under anticipated environmental conditions.

(5) Ratio-type a.c. analog computers are used to accomplish the required computations in a minimum of space and weight. They provide high accuracy and a minimum of field adjustments.

Description of the Model 120

The Model 120 automatic navigation and flight control system comprises a Doppler ground-velocity sensor, navigational computer, heading and vertical references, a dead-reckoning position indicator, and an integrated flight-attitude instrumentation system. It

Mr. Iverson is Assistant Group Engineer in the Systems Analysis Section of the Electronics Division.

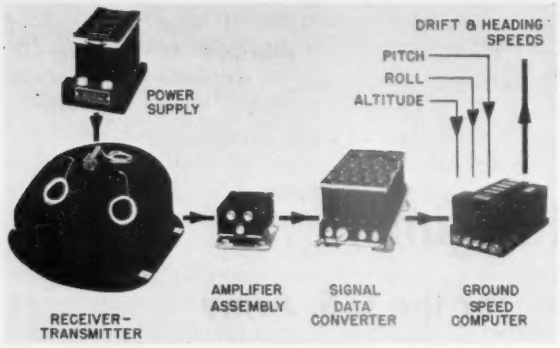

FIG. 1. Pictorial block diagram of the continuous-wave, Doppler-type, airborne ground velocity indicator employed in the Model 120 navigation system.

is a lightweight, self-contained airborne system suitable for fixed and rotary-wing U.S. Army aircraft. It automatically, continuously, and accurately computes and displays ground speed, drift angle, ground position, ground track, wind speed and direction, course- and distance-to-destination, aircraft attitude, and heading. It operates on a world-wide basis over all types of terrain under all-weather conditions. This system may be used for point-to-point navigation, observation, traffic control, approach and landing, and many other special missions.

The Model 120 is an outgrowth of the AN/APN-67 automatic navigator developed for the Navy Bureau of Aeronautics. Research leading toward the APN-67 development was accomplished by the Navy Research Laboratory, starting with a project established in 1933. Development of the APN-67 began in 1951 and has since led to the current pilot-line production of the system.

The Army's first self-contained Doppler Navigator, the Model 103, was delivered to the Army Electronic Proving Grounds, Fort Huachuca, Arizona in October, 1956. The system was evaluated in an L-20 aircraft and has clearly demonstrated the value of this type navigation equipment in Army aircraft. The second Army Automatic Doppler Navigator to be flight tested was also developed by Ryan. It is an advanced system designated the Ryan Model 108 and was delivered to AEPG early in 1958. Model 120 is an integrated system which incorporates the Model 108 as the Doppler navigation equipment. Deliveries of the Model 120 for service evaluation will be completed during the second quarter of this year. Installations are being made in H-19 and H-34 helicopters and L-20 aircraft. The systems will be tested in a variety of missions under all-weather and combat conditions to demonstrate the value of such systems in Army aircraft.

The operational characteristics of the Model 120A for fixed-wing applications are shown in Table 1.

The ground-speed coverage of the Model 120B for rotary-wing application is -150 to $+300$ knots, and the drift angle coverage is unlimited. The hovering sensitivity is set at approximately 1/2 knot which allows a very tight hover to be maintained.

The physical characteristics of the Model 120A are shown in Table 2.

The Model 120B total weight is increased by 15 lbs., the antenna volume is increased by 1/2 cu.ft., and the aperture area is increased by 3/4 sq.ft.

The Doppler ground-velocity indicator employed in the Model 120 is illustrated in the pictorial block diagram in Fig. 1. The weight of the ground-velocity indicator is approximately 80 lbs. The receiver-transmitter radiates two narrow-beams of continuous-wave energy; the beams are directed downward, outward, and either fore or aft. A portion of the energy radiated by the receiver-transmitter reaches the earth and is reflected back to the antenna. The aircraft velocity can be resolved into components along these beams; therefore, the returned energy along each beam experiences a shift in frequency directly proportional to this velocity. The frequency shift is known as the Doppler effect. The Doppler signals are detected in the microwave crystal mixers by a direct-to-audio technique which requires no intermediate frequency. The detected signals from the receiver-transmitter are supplied to the signal data converter which automatically searches for, acquires, and tracks the signals to provide analog outputs proportional to the Doppler frequencies. Simple geometry shows that for normal level flight, the sum of these frequencies is proportional to aircraft speed in the heading direction, the difference is proportional to speed in the drift direction. However, since the receiver-transmitter is fixed to the aircraft, correction must be applied for deviations in aircraft attitude and vertical speed from normal level flight. The Doppler signals are applied to the ground-speed computer which stabilizes the data for aircraft pitch, roll, and vertical speed. The outputs of this unit,

TABLE 1
Operational Characteristics

Ground speed	25 to 300 knots
Drift angle	0 to 45°
Vertical speed	0 to ±6,000 fpm, or greater
Altitude	0 to 25,000 ft.
Range	At least 500 nautical miles without reset
Attitude	±80° pitch and roll
Accuracy	1 to 2% of distance traveled from last fix

TABLE 2
Physical Characteristics

Type of system	CW Doppler; two fixed beams of radiation; data stabilization
Approximate weight	150 lbs.
Approximate volume (excluding antenna)	3.9 cu.ft.
Approximate installed antenna volume	1 cu.ft.
Radome aperture	1¾ sq.ft.
Antenna beamwidth (two-way)	4°
Approximate transmitter power	1 watt
Transmitter frequency	13,500 mc./sec.
Approximate power consumption	450 watts

heading and drift speeds, are orthogonal components of the aircraft ground velocity.

The aircraft ground-speed components are supplied to the navigational computer indicator shown in Fig. 2 which resolves them about true heading to obtain North-South and East-West ground-speed components. These ground-speed components are integrated and converted to changes in latitude and longitude. The navigational computer indicator determines the wind speed and direction. A wind memory feature allows accurate navigation based on last available wind data and true air speed during periods of radar silence. Additionally, the navigational computer indicator computes the course- and distance-to-destination or to the base. The navigational computer and the bearing and distance indicator are modified ASN-16 equipments developed by Clifton Precision Products, Clifton Heights, Pa. A contact analog navigation indicator, the dead-reckoning position indicator, is also supplied as part of the Model 120. This unit provides an illuminated bug which indicates aircraft position on a map overlay or a grid coordinate system and heading on a compass rose. Therefore, the pilot is presented with graphic indication of his present position with respect to his destination, his base, and any known obstacles in the area. The DRPI has proved to be a very successful read-out device for short-range navigation.

The visual indications provided by Model 120 indicators are:

- Ground speed
- Drift angle
- Wind speed
- Wind heading
- Ground track
- Relative bearing-to-destination (or base)
- Course error
- Range-to-destination (or base)
- Pictorial display of position and heading
- Present latitude
- Present longitude
- Destination latitude
- Destination longitude
- Magnetic variation
- Aircraft heading
- Desired heading
- Aircraft attitude (pitch and roll)
- Aircraft turning rate

The Lear MA-1 gyro stabilized magnetic compass system is used as the heading reference. A feature added to the basic MA-1 is automatic heading capture incorporated to provide automatic operation. Both the vertical reference and the heading reference are deslaved during aircraft turns to minimize errors.

The receiver-transmitter installed flush-mounted in an L-20 aircraft is shown in Fig. 3. It comprises a divided reflector, radome installation shroud, waveguide, microwave crystal mixers, and the klystron transmitter. These items are rigidly joined to form a single sealed beam assembly. The microwave circuitry which is sealed in the septum has no moving parts and requires no adjustments. Only the transmitter and microwave crystal mixers may require replacement and these are readily available at the top of the unit.

With continuous-wave radar, transmission and reception occur simultaneously. It is necessary to separate these functions; the proved method of separation is termed "space duplexing" wherein transmission and reception employ different antennas. The unique design of Model 120 receiver-transmitter allows space duplexing in a single assembly. The radar reflector is divided into two parts by a septum (which also contains the microwave circuitry).

The Doppler signals are detected by a direct-to-audio technique. In this method of signal detection, a small portion of the transmitted energy is coupled into the microwave crystals to serve as the local oscillator signal. The returned energy, shifted by the Doppler frequency, is also introduced to the crystal, mixes with

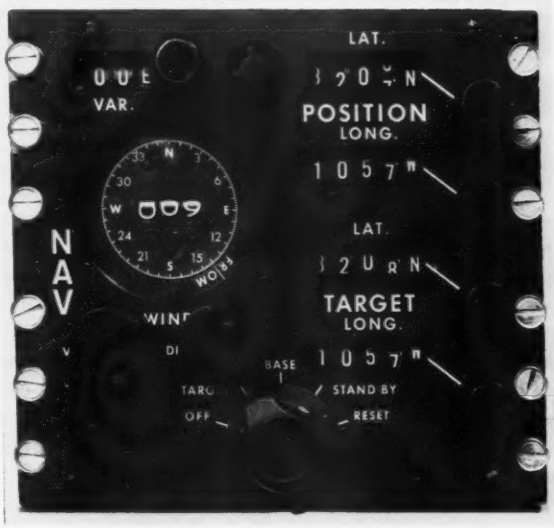

FIG. 2. Navigational computer indicator displaying present position, destination position, wind speed, wind direction, and magnetic variation.

FIG. 3. Flush mounted receiver-transmitter installed in a U.S. Army L-20 aircraft.

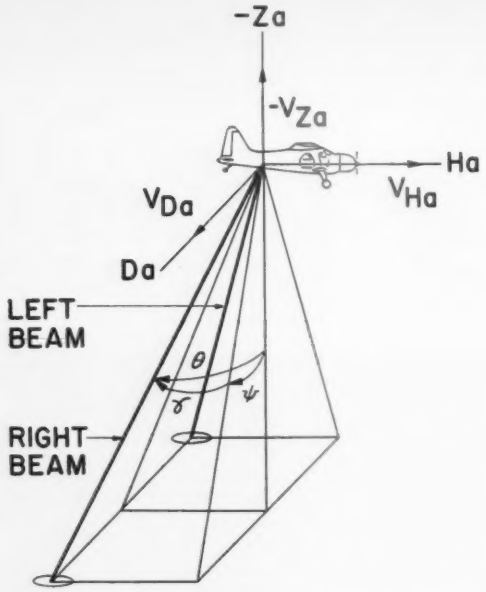

FIG. 4. Orientation of the fixed radar beams in aircraft referenced coordinates.

the local oscillator, and produces the audio Doppler signal directly. There is no intermediate frequency; I.F. amplifiers and automatic frequency control are not required. The result is the simplest, most reliable method of signal detection.

DERIVATION OF EQUATIONS

Doppler ground velocity indicators employ two or more radar beams which may be fixed with respect to the aircraft or stabilized about one or more axes. The Model 120A developed for fixed-wing Army aircraft uses two radar beams installed fixed with respect to the airframe. Four radar beams are employed in rotary wing applications where vertical speed indications and hovering capabilities are required. The two beam system requires that the Doppler data be stabilized for aircraft attitude and vertical motion in order to obtain the aircraft ground velocity component. The equations are derived below.

The two radar beams are directed outward and either fore or aft on each side of the aircraft as shown in Fig. 4. The beams are oriented in the aircraft coordinates (H_a, D_a, and Z_a) by the angles shown where $\theta = 24.5°$, $\gamma = 22°$, and $\psi = 11°$. The two beams of energy formed by the single antenna assembly are radiated towards the earth. A portion of the energy is reflected back to the receiving antenna. The received frequency differs from the transmitted frequency by the Doppler shift which is directly proportional to the aircraft velocity components on the radar beams. The starboard and port Doppler frequencies are:

$$D_S = (2/\lambda)\ (-C\ V_{Da} + A\ V_{Ha} - B\ V_{Za}) \qquad (1)$$

$$D_P = (2/\lambda)\ (C\ V_{Da} + A\ V_{Ha} - B\ V_{Za}) \qquad (2)$$

where λ is the transmitter wavelength (2.22 cm.), and A, B, and C are antenna installation angle constants ($A = \sin\gamma$, $B = \cos\gamma\cos\psi$, $C = \cos\gamma\sin\psi$).

The Doppler sense need not be detected for normal navigation and it is assumed that

$$|A\ V_{Ha}| > |B\ V_{Za}| + |C\ V_{Da}| \qquad (3)$$

The Doppler frequency on each radar beam is detected by the direct-to-audio (no I.F. frequency) signal detection technique previously described. The signal data converter accurately measures the center of power of the Doppler signals and provides proportional analog outputs. The sum and difference Doppler frequencies are given by the following equations:

$$(D_P + D_S) = (4A/\lambda) + [V_{Ha} - (B/A)\ V_{Za}] \qquad (4)$$

$$(D_P - D_S) = (4C/\lambda)\ V_{Da} \qquad (5)$$

Aircraft coordinates are displaced from the earth referenced coordinates by the aircraft pitch and roll angles. Relationships between the aircraft and earth referenced coordinates are given by the following matrix of direction cosines.

		Earth Coordinates		
		H	D	Z
Aircraft Coordinates	H_a	$\cos P$	0	$-\sin P$
	D_a	$\sin R \sin P$	$\cos R$	$\sin R \cos P$
	Z_a	$\cos R \sin P$	$-\sin R$	$\cos R \cos P$

(6)

The positive direction of roll is right wing down and the positive direction of pitch is nose up. The coordinate conversion from one set of coordinates to the other is readily accomplished by means of two electrical resolvers and associated amplifiers.

The heading and drift speed are defined as the components of ground speed in the direction of aircraft heading and transverse to aircraft heading respectively. These speed components are equivalent to ground speed and drift angle. The heading and drift speeds are determined in terms of sums and differences of the Doppler frequencies, aircraft pitch and roll angles, and vertical rate.

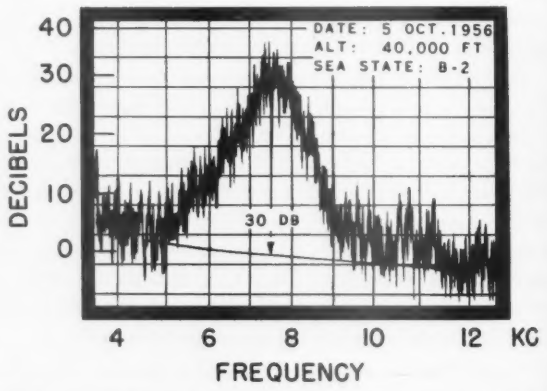

FIG. 5. Typical Doppler spectrum obtained with ground velocity indicator installed in a T-33 jet trainer.

$$V_H = \frac{1}{\cos R \cos P - (B/A) \sin P} \left[-\frac{\lambda}{4C} (D_P - D_S) \frac{B}{A} \sin R + \frac{\lambda}{4A} (D_P + D_S) \cos R + V_Z \left(\cos R \sin P + \frac{B}{A} \cos P \right) \right] \quad (7)$$

$$V_D = \frac{1}{\cos R \cos P - (B/A) \sin P} \left[\frac{\lambda}{4C} (D_P - D_S) \left(\cos P - \frac{B}{A} \sin P \cos R \right) - \frac{\lambda}{4A} (D_P + D_S) \sin R \sin P - V_Z \sin R \right] \quad (8)$$

These equations are readily solved by electrical analog techniques in the ground-speed computer. The sum and difference of the two Doppler frequencies are obtained by the use of transformers. Vertical speed (V_Z) is derived from a simple barometric altitude data transmitter via a follow-up servo. The coordinate resolution through aircraft pitch and roll angles by means of two electrical resolvers completes the solution for the heading and drift speeds. No practical attitude limitations are imposed by this computer. The ground speed (V_g) and drift angle (δ) are obtained by resolution of the heading and drift speeds in the ground-speed/drift-angle indicator.

The Doppler Signal

The radar energy is transmitted in a narrow pencil beam and the return from the earth's surface is spectral in nature with the spread in Doppler frequencies roughly corresponding to the beamwidth of the radar beam. The Doppler spectrum is characterized by the center frequency, the bandwidth, and the signal-to-noise density ratio.

The signal data converter searches for, acquires, tracks, and measures each Doppler spectrum and provides a precise 400 cps signal whose amplitude corresponds to the center-of-power Doppler frequency. The center-of-power frequency depends on the aircraft velocity, installation angles, transmitter frequency, and surface reflection coefficient. The surface reflection coefficient of land is essentially linear over the antenna beamwidth. However, over sea the coefficient varies greatly over the beamwidth, this causes a spectral shift known as sea bias. A land-sea switch corrects for the average sea bias resulting in accurate measurement over land or sea:

The width of the Doppler spectrum depends directly on antenna beamwidth and beam installation angles. The spectral width is a constant percentage of the Doppler frequency for a given system design.

The signal-to-noise density ratio of the Doppler signal depends on system parameters and the surface reflection coefficient. The signal-to-noise density ratio derived from the radar range equation is given below.

$$\left(\frac{S}{N}\right)_d \sim \frac{P_T G_0 \lambda^2 \sigma_0 \cos\theta \tan\gamma (K)}{A^2 \beta_\theta F k T} \quad (9)$$

where P_T is transmitted power, G_0 is antenna gain, λ is the transmitter wavelength, σ_0 is the surface reflection coefficient (defined as radar cross section per unit surface area), θ and γ are antenna angles, K is an antenna parameter, A is aircraft altitude, β_θ is the two-way antenna beamwidth, F is the crystal noise figure at the Doppler frequency, k is Boltzmann constant, and T is absolute temperature in °K. It should be noted that the signal-to-noise density ratio varies with the square of altitude instead of the fourth power as would be indicated by the usual radar range equation. This is a result of the fact that the area of the earth's surface intersected by the radar beam increases with the square of altitude. Also, it should be noted that in a direct-to-audio type detection system the signal-to-noise density ratio is independent of speed. This effect results from the interaction of two compensating effects. The Doppler signal density decreases in direct proportion with increasing speed. However, in a direct-to-audio system, the microwave crystal noise density also decreases in direct proportion with increasing speed.

A typical Doppler spectrum derived from a system similar to that utilized in the Model 120 ground velocity indicator is shown in Fig. 5. This was obtained with a system installed in the wing tank of a T-33 jet trainer.

The Model 120 integrated navigation and flight instrumentation system described in this paper is an advanced system designed for U.S. Army fixed- and rotary-wing aircraft. Similar Doppler systems developed by Ryan are currently available for most jet and propeller-driven aircraft, helicopters, airships, and some missile types. These systems are characterized by simplicity, reliability, and maintainability resulting largely from the use of the direct-to-audio continuous-wave Doppler radar.

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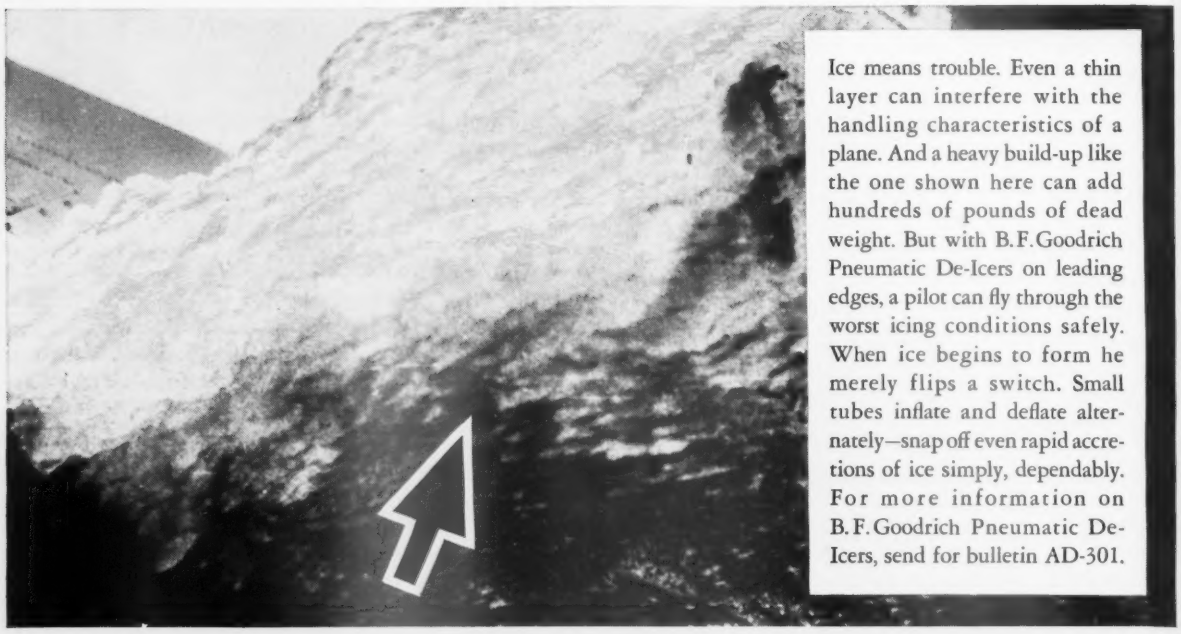
B.F.Goodrich De-Icers could have prevented this



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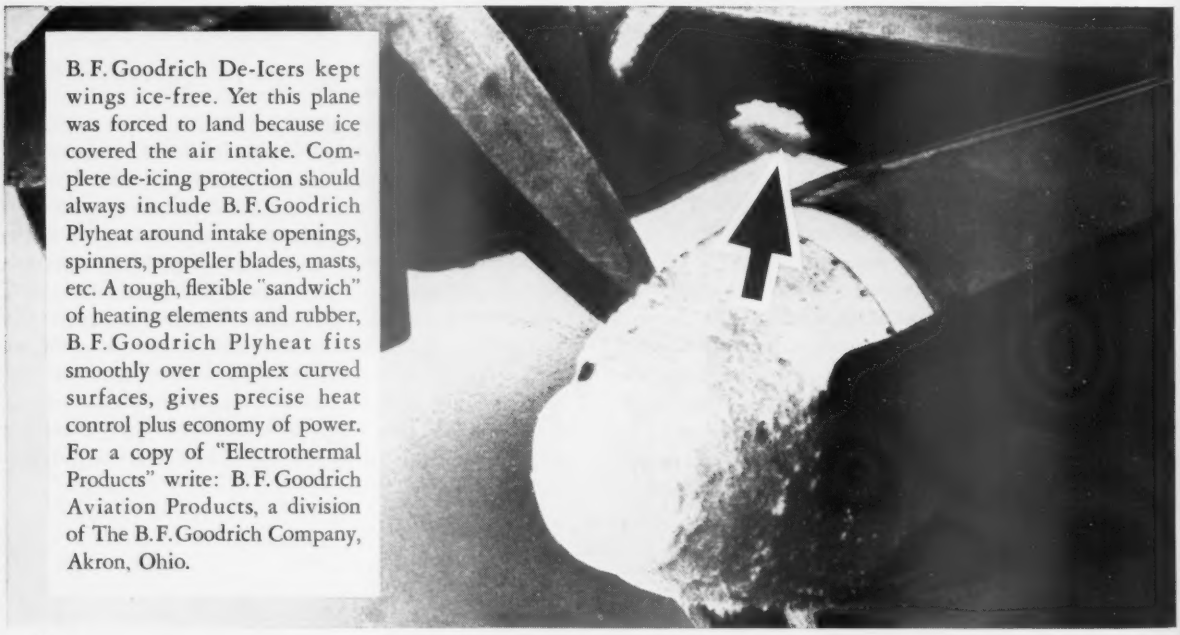

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PERIODICALS AND REPORTS 88

INTERNATIONAL AERONAUTICAL ABSTRACTS. 99

BOOKS 155

Subject Index to Periodicals & Reports

Acoustics, Sound, & Noise 88
Aerodynamics
- Aerothermodynamics 88
- Boundary Layer 88
- Control Surfaces 88
- Fluid Mechanics & Aerodynamic Theory 88
- Internal Flow 91
- Stability & Control 93
- Wings & Airfoils 94

Aeroelasticity 96
Aeronautics, General 96
Air Transportation 96
Airplane Design 96
- Air Conditioning & Pressurization 98
- Control Systems 98
- Landing Gear 98

Airports 98
Aviation Medicine 98
- Human Engineering 98

Computers 98
Education & Training 116
Electronics 116
- Amplifiers 116
- Antennas 116
- Circuits & Components 116
- Communications 116
- Electronic Tubes 118
- Measurement & Testing 118
- Noise & Interference 118
- Oscillators & Signal Generators 118
- Radar 118
- Semiconductors 119
- Telemetry 119
- Wave Propagation 119

Equipment
- Electric 122
- Hydraulic & Pneumatic 122

Flight Operating Problems 122
Flight Testing 122
Fuels & Lubricants 122
Ice Formation & Prevention 122
Instruments 122
- Automatic Control 122
- Flow Measuring Devices 124
- Pressure Measuring Devices 124
- Vibration Measuring Devices 124

Laws & Regulations 124
Machine Elements 124
- Bearings 124

Materials 124
- Ceramics & Ceramals 124
- Corrosion & Protective Coatings 124
- Metals & Alloys 124
- Metals & Alloys, Ferrous 126
- Metals & Alloys, Nonferrous 126
- Nonmetallic Materials 126

Mathematics 126
Mechanics 132
Meteorology 132
Military Aviation & Armament 132
Missiles 132
Navigation 136
- Electronic Aids 136

Nuclear Energy 136
Parachutes 136
Photography 136
Physics 136
Power Plants
- Jet & Turbine 140
- Ram-Jet & Pulse-Jet 142
- Reciprocating 142
- Rocket 142

Production 142
- Metalworking 142
- Nonmetalworking 142
- Production Engineering 142

Propellers 144
Rotating Wing Aircraft 144
Safety 144
Space Travel 144
Structures 146
- Beams & Columns 146
- Cylinders & Shells 146
- Elasticity & Plasticity 146
- Plates 148
- Thermal Stress 148

Thermodynamics 148
- Combustion 148
- Heat Transfer 149

VTOL & STOL 149
Wind Tunnels & Research Facilities 149

Acoustics, Sound, & Noise

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Aerothermodynamics

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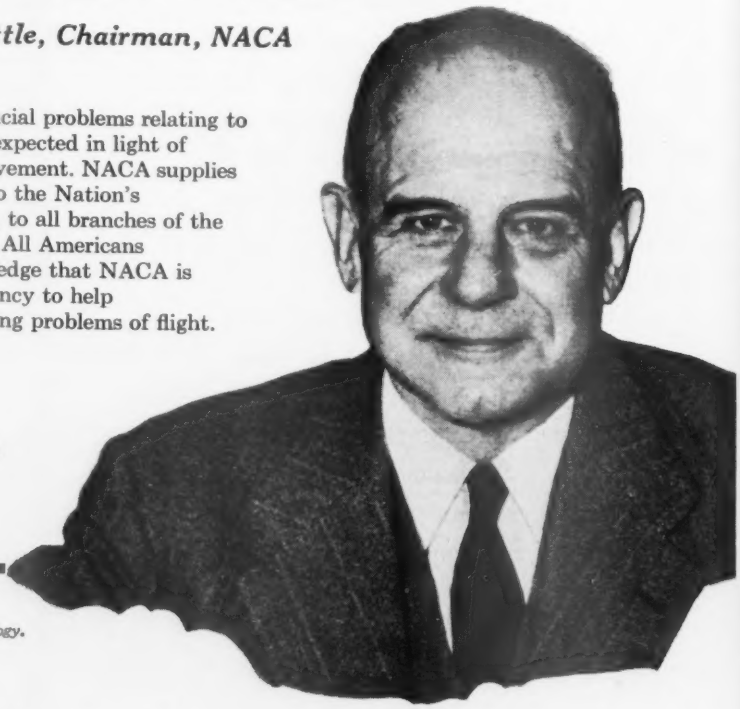

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Low-Speed Static Stability Characteristics of a Cambered-Delta-Wing Model. John M. Riebe and William C. Moseley, Jr. *U.S., NACA RM L55L21a*, Mar. 8, 1956. 27 pp. 10 refs. Wind-tunnel investigation at several wing dihedral angles in combination with a circular fuselage and various tail configurations.

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Investigation at High Subsonic Speeds of the Static Longitudinal Stability Characteristics of a Model Having Cropped-Delta and Unswept Wing Plan Forms and Several Tail Configurations. Albert G. Few, Jr. *U.S., NACA RM L55I23a*, Nov. 30, 1955. 107 pp. Study indicating that none of the tail arrangements used with the unswept wing are capable of producing essentially linear pitching-moment curves for the complete model. Reasonably linear pitching-moment characteristics are obtained with several tail arrangements in conjunction with the cropped-delta-wing model.

Longitudinal Aerodynamic Characteristics of a Model Airplane Configuration Equipped with a Scaled X-1 Airplane Wing. James H. Parks. *U.S., NACA RM L51L10a*, Apr. 11, 1952. 37 pp. 14 refs. Investigation in which aerodynamic derivatives defining the static and dynamic longitudinal stability, control, trim, and drag characteristics of the configuration are obtained over a Mach Number range from 0.6 to 1.17.

Effects of Leading-Edge Radius on the Longitudinal Stability Characteristics of Two 60° Sweptback Wings at High Reynolds Numbers. William C. Schneider. *U.S., NACA RM L55-L30*, Mar. 19, 1956. 46 pp. Wind-tunnel investigation on two wings of aspect ratio two and three at Mach Numbers from 0.05 to 0.30. Little effect on the inflection lift coefficient was noted when the leading-edge radius was increased, for both wings. Small Reynolds Number effects were found for wings of aspect ratio three, and only slightly larger effects were noted for the wings of aspect ratio two.

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Wings & Airfoils

Effect of Some Section Modifications and Protuberances on the Zero-Lift Drag of Delta Wings at Transonic and Supersonic Speeds. Carl A. Sandahl and William E. Stoney. *U.S., NACA RM L53L24a*, Feb. 18, 1954. 43 pp. Presentation of results from free-flight rocket tests to determine the effect of leading-edge radius and airfoil aftersection thickening on the zero-lift drag. In addition, one configuration employed simulated control-actuator housings.

An Application of Crocco's Stream Function to the Study of Rotational Supersonic Flow Past Airfoils. Abraham Kogan. (*Technion Res. Devel. Found., Haifa, TN; AFOSR TN 56-165*, 1956.) *Quart. J. Mech. & Appl. Math.*, Feb., 1958, pp. 1–23. 17 refs. USAF-sponsored development of a method of successive approximations for the ideal flow around airfoils at high supersonic Mach Numbers, based on the concept of Crocco's stream function.

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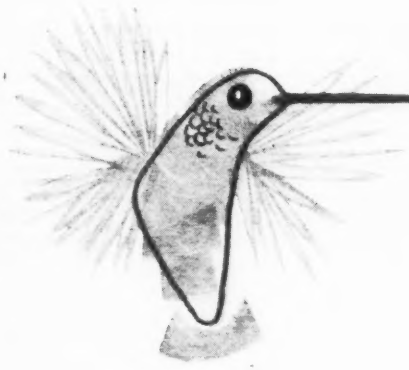

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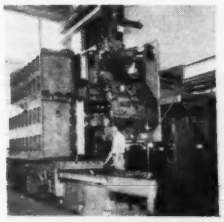

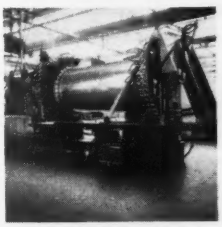

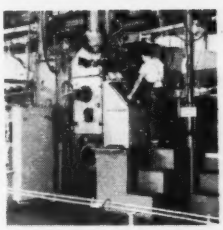

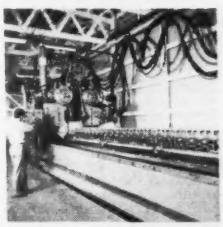

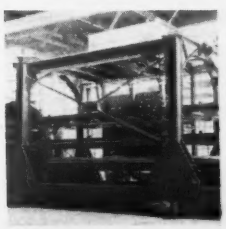

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(*Continued on page 116*)

INTERNATIONAL AERONAUTICAL ABSTRACTS

A Review of Worldwide Scientific and Technical Literature

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PUBLISHED MONTHLY BY AERO/SPACE ENGINEERING

Official Publication of the Institute of the Aeronautical Sciences, 2 East 64th Street, New York 21, N.Y.

Volume 3, Number 5 May, 1958

ACOUSTICS, SOUND, & NOISE

TUNED SPOT DAMPERS FOR AIRCRAFT SOUNDPROOFING; A FEASIBILITY AND DEVELOPMENT STUDY. H. F. Reiher, R. N. Hamme, and R. E. Hamilton. USAF WADC TR 57-519 [AD 131081], Oct., 1957. 174 pp. Presentation of detailed sound transmission measurements in the potentially resonant range of frequencies for a simulated aircraft fuselage section. Design parameters are investigated extensively by a free-vibration criterion of damping effectiveness, and correlations are developed between the damping criterion, the response of steady-state excitation, and the resonant sound transmission of panel structures.

NOISE SURVEY UNDER STATIC CONDITIONS OF A TURBINE-DRIVEN FULL-SCALE MODIFIED SUPERSONIC PROPELLER WITH AN ADVANCE RATIO OF 3.2. M. C. Kurbjun. US, NACA TN 4172, Jan., 1958. 17 pp. Measurement of overall sound-pressure levels and frequency spectra of the noise emitted from a 10-foot-diameter, 1,700-r.p.m. three-blade modified supersonic propeller mounted on a turbine-powered airplane under static conditions around a circle with a 100-foot radius about the propeller hub. The results are compared with those for a supersonic and a conventional subsonic propeller. The effects of power and rotational speed change on the noise levels and spectra are also shown.

REVERBERATION CHAMBER STUDY OF THE SOUND POWER OUTPUT OF SUBSONIC AIR JETS. R. V. Waterhouse and R. D. Berendt. ASA J., Feb., 1958, pp. 114-121. 16 refs. Investigation to determine the sound spectra and acoustic power radiated by air jets over a range of subsonic velocities. Different air jets are used with sound and square velocity profiles; nozzles of circular cross section and nozzles with saw-tooth and corrugated ends are also used. Of these nozzles only the latter type gave a significant (9 db) reduction in sound power output for a given pressure ratio. A study is made on the limitations of the reverberation chamber technique caused by the absorption in the chamber. When this absorption becomes considerable, the measurement of sound pressure level in a circle around the sound source revealed a direction pattern, and the assumption of uniform energy distribution in the chamber became invalid.

AERODYNAMICS

Aerothermodynamics

ON THE HEAT TRANSFER TO CONSTANT-PROPERTY LAMINAR BOUNDARY LAYER WITH POWER-FUNCTION FREE-STREAM VELOCITY AND WALL-TEMPERATURE DISTRIBUTIONS. Isao Imai. Quart. Appl. Math., Apr., 1958, pp. 33-45. 12 refs. Analysis of heat transfer by means of an improved version of the previously developed WKB method. As an example the Blasius flow and stagnation flow are considered for several values of n, and the results are compared with the purely numerical computations by Levy and by Chapman and Rubesin, as well as with the analytical approximate formulas obtained by Schuh, Fettis, and Lighthill.

Boundary Layer

THE SOLUTION OF COMPRESSIBLE LAMINAR BOUNDARY LAYER PROBLEMS BY A FINITE DIFFERENCE METHOD. II - FURTHER DISCUSSION OF THE METHOD AND COMPUTATION OF EXAMPLES. D. C. Baxter and Irmgard Flügge-Lotz. Stanford U., Div. Eng. Mech. TR 110 (AFOSR TN 58-1) [AD 148040], Oct. 15, 1957. 220 pp. 81 refs. Application of a finite difference solution of the corresponding differential equations to the investigation of the compressible boundary layer with variable pressure gradient and wall temperature. The Crocco form of the equations is used; the method is programmed on an IBM 650 digital computer; the Prandtl Number is assumed constant at 0.72; and the Sutherland viscosity law

is introduced. With the exception of flows which involve overshoot, the method will allow determination of boundary-layer behavior under any combination of pressure gradient and wall temperature or heat flux variation. It is limited only in that (a) starting profiles must be provided at some distance downstream of the nose and (b) the time required to compute a particular example of interest may be long. Includes investigation of the stability of the numerical solution of boundary-layer equations; consideration of several examples involving flow over nonisothermal flat plates where the pressure gradient is zero; and comparison of heat-transfer results to the specializations and extensions of Lighthill's results.

THE SOLUTION OF COMPRESSIBLE LAMINAR BOUNDARY LAYER PROBLEMS BY A FINITE DIFFERENCE METHOD. III - THE INFLUENCE OF SUCTION OR BLOWING AT THE WALL. Irmgard Flügge-Lotz and J. T. Howe. Stanford U., Div. Eng. Mech. TR 111 (AFOSR TN 58-2) [AD 148041], Oct. 15, 1957. 44 pp. Investigation of the influence of a transverse velocity at a porous wall on skin friction, heat transfer, and laminar separation. A modification of the finite difference scheme is used to include the transverse velocity effects in the computation at the wall point. Series expansions involving the shear stress and the enthalpy derivative are employed at each wall point. A number of examples are presented illustrating the flow over both hot and cold walls, and examples with and without pressure gradient are discussed.

AN APPROXIMATE BOUNDARY-LAYER THEORY FOR SEMIINFINITE CYLINDERS OF ARBITRARY CROSS-SECTION. E. Varley. Brown U., Div. Appl. Math. Rep. (AFOSR TN 58-53) [AD 148095], Jan., 1958. 27 pp. Presentation of an estimate for the distribution of skin frictional force per unit length and of displacement area on the outside of a semiinfinite cylinder of arbitrary cross-section, moving steadily in a direction parallel to its generators. The Pohlhausen method is used with a velocity distribution selected to yield zero viscous retarding force on the boundary layer approximations. Results for the elliptic cylinder and finite flat plate are given in closed form, as well as an estimate of the effect of corners on skin frictional force and displacement area.

EFFECT OF MACH NUMBER ON BOUNDARY-LAYER TRANSITION IN THE PRESENCE OF PRESSURE RISE AND SURFACE ROUGHNESS ON AN OGIVE-CYLINDER BODY WITH COLD WALL CONDITIONS. R. J. Carros. US, NACA RM A56B15, Apr. 20, 1956. 30 pp. 21 refs. Free flight investigation on transition at Mach Numbers varying from 1.8 to 7.4. Results show that increasing Mach Number has a very favorable effect of increasing the extent of the laminar boundary layer for a given surface roughness. The transition data, when plotted as a function of a factor indicative of heat transfer, shows that heat transfer is possibly responsible for a good deal of the increase in transition Reynolds Number with Mach Number. The results also show that Mach Number, surface roughness, pressure rise, and Reynolds Number are found to influence transition in the Lees-Van Driest region of predicted infinite laminar stability.

INVESTIGATION OF EFFECTS OF DISTRIBUTED SURFACE ROUGHNESS ON A TURBULENT BOUNDARY LAYER OVER A BODY OF REVOLUTION AT A MACH NUMBER OF 2.01. Appendix - ESTIMATION OF CHANGE IN LAMINAR-SUBLAYER THICKNESS FROM M = 1.61 TO M = 2.01. J. R. Sevier, Jr., and K. R. Czarnecki. US, NACA TN 4183, Feb., 1958. 31 pp. Tests on three ogive cylinders at zero angles of attack over a surface-roughness range from 23 to 480 microinches root mean square and for a Reynolds Number range based on body length from 4×10^6 to 30×10^6. Results show that distributed surface roughness effects are similar to those at a Mach Number of 1.61 and at subsonic speeds, i.e., for a given roughness height, some critical Reynolds Number exists at which the skin-friction law begins to depart from the classical turbulent skin-friction law because of the form drag of the individual roughness particles. It is further shown that increasing the Mach Number from 1.61 to 2.01 increases the allowable roughness for a turbulent boundary layer by about 40%. This increase is in good agreement with that predicted on the basis of a constant ratio of allowable roughness height to laminar-sublayer thickness or to a constant value of the Reynolds Number based on allowable roughness height, shearing-stress velocity, and local conditions at the surface.

EFFECT OF DISTRIBUTED GRANULAR-TYPE ROUGHNESS ON BOUNDARY-LAYER TRANSITION AT SUPERSONIC SPEEDS WITH AND WITHOUT SURFACE COOLING. A. L. Braslow. US, NACA RM L58A17, Mar. 10, 1958. 22 pp. 14 refs. Experimental investigation on a 10° cone made at Mach Numbers of 2.01 and 1.61. The critical value of the roughness Reynolds Number at the higher speeds is determined. The results indicate that the transitional-triggering mechanism of distributed three-dimensional particles is the same at supersonic and subsonic speeds. The value of the three-dimensional roughness Reynolds Number parameter $\sqrt{R_k}, t$ is approximately the same at supersonic and subsonic speeds. For a given stream Mach Number and Reynolds Number, surface cooling will promote transition due to existing three-dimensional roughness. At a Reynolds Number less than its critical value, the roughness introduces no disturbances of sufficient magnitude to influence transition.

BOUNDARY-LAYER DISPLACEMENT EFFECTS IN AIR AT MACH NUMBERS OF 6.8 AND 9.6. Appendix A - LEADING-EDGE-THICKNESS EFFECTS. Appendix B - EFFECT OF VARIABLE γ AND GASEOUS IMPERFECTIONS. Appendix C - SKIN FRICTION OF A FLAT-PLATE WING WITH DELTA PLAN FORM INCLUDING BOUNDARY-LAYER

DISPLACEMENT EFFECT. Appendix D - SKIN FRICTION OF A FLAT-PLATE DELTA WING WITH BOUNDARY-LAYER TRANSITION. M. H. Bertram. US, NACA TN 4133, Feb., 1958. 61 pp. 26 refs. Presentation of measurements for pressure gradients induced by laminar boundary layer on a flat plate. The measured pressure distribution was predicted with good accuracy by a modification of the insulated-plate displacement theory which allows for the effect of heat transfer and temperature gradient along the surface on the boundary-layer displacement thickness. The total drag of thin wings with square and delta plan forms was measured at a nominal Mach Number of 6.8 over a wide range of Reynolds Numbers. The total drag was found to be greater than can be explained by adding a classical value of laminar skin friction to the estimated pressure drag. The difference is explained by the increase in skin friction caused by the boundary-layer-induced pressures.

A SIMPLIFIED FORM OF THE AUXILIARY EQUATION FOR USE IN THE CALCULATION OF TURBULENT BOUNDARY LAYERS. T. J. Black. Gt. Brit., ARC CP 370, 1958. 19 pp. 10 refs. BIS, New York, $0.45. Derivation of a new type of auxiliary equation for calculating the development of the form-parameter H in turbulent boundary layers with adverse pressure gradients. This has been achieved by extending part of the previous analysis by Spence. Several results of the calculations are compared with experiment. Attention is drawn to the similarity between the form of the new equation and that of Schuh's auxiliary equation.

Control Surfaces

JET DRAG OF WINGS WITH JET FLAPS. Appendix I - THE AMOUNT OF FREE AIR ENTRAINED IN A SUBSONIC JET. Appendix II - EFFECT OF A PROPULSIVE JET EMERGING FROM A SLOT FORWARD OF THE TRAILING EDGE. P. R. Payne. Aircraft Eng., Mar., 1958, pp. 73-81. Analysis considering the density of the jet before and after mixing with free-stream air in which it is shown that Stratford's equation for jet density after mixing is accurate only for the case where the jet is cold. The flux of momentum behind an airfoil with jet flap is examined, using the basic Stratford's approach, but with the difference that the density correction factor K is included in the analysis and an exact solution to the equation is obtained. It is suggested that contrary to Stratford's hypothesis momentum flux has little relationship to the force acting on the airfoil, because there is no mechanism whereby the momentum flux may be converted into a thrust force on the wing. The mechanism of jet drag is shown by the construction of a potential flow model.

Fluid Mechanics & Aerodynamic Theory

AN ENERGY PRINCIPLE FOR HYDROMAGNETIC STABILITY PROBLEMS. I. B. Bernstein, E. A. Frieman, M. D. Kruskal, and R. M. Kulsrud. Royal Soc. (London) Proc., Ser. A, Feb. 25, 1958, pp. 17-40. 20 refs. Analysis of the stability of static, highly conducting, fully ionized plasmas by means of an energy principle developed from one introduced by Lundquist. The derivation of the principle and the conditions under which it applies are given. The method is used to find complete stability criteria for two types of equilibrium situations. The first concerns plasmas which are completely separated from the magnetic field by an interface. The second is the general axisymmetric system.

HYDROMAGNETIC STABILITY OF A CONDUCTING FLUID IN A CIRCULAR MAGNETIC FIELD. F. N. Edmonds, Jr. Phys. Fluids, Jan.-Feb., 1958, pp. 30-41. 13 refs. USAF-supported extension of the theory for viscous flow between two rotating coaxial cylinders as developed by Taylor and Chandrasekhar to the case when the fluid is an electrical conductor and a circular magnetic field is present. The equations governing marginal stability are derived, and boundary conditions for perfectly conducting cylinders (Fermi boundary conditions) are formulated for two cases when the difference in cylinder radii is small compared to their mean.

ON MAGNETOHYDRODYNAMIC WAVES AND MAGNETIC TANGENTIAL DISCONTINUITIES IN RELATIVISTIC HYDRODYNAMICS. I. M. Khalatnikov. (Zhurnal Exper. i Teoret. Fiz., May, 1957, pp. 1, 092-1, 097.) Sov. Phys. - JETP, Dec., 1957, pp. 901-905. Translation. Derivation of equations for the velocity of waves in the presence of a magnetic field making an arbitrary angle with the direction of propagation of the waves in a medium with an arbitrary equation of state. The properties of purely magnetic tangential discontinuities in relativistic hydrodynamics are also discussed.

ON THE DIFFUSION OF A CHEMICALLY REACTIVE SPECIES IN A LAMINAR BOUNDARY LAYER FLOW. P. L. Chambré and J. D. Young. Phys. Fluids, Jan.-Feb., 1958, pp. 48-54. 14 refs. ONR-supported investigation of a certain class of homogeneous volume reactions in fluid flow. A chemically reactive species is emitted from the surface of a body located in a hydrodynamic flow field. It diffuses into the fluid where it undergoes a simple isothermal homogeneous transformation. The analysis given enables the reaction history of this component to be traced over the surface of a body. The development of a first-order reaction in the neighborhood of a flat plate is calculated. Two types of reactions are considered: in one case the reactant is destroyed; in the other, it is generated.

THE EQUATIONS OF MOTION IN A MULTICOMPONENT CHEMICALLY REACTING GAS (RESEARCH MEMORANDUM No. 5). S. M. Scala. G-E MOSD TIS R58SD205, Dec. 20, 1957. 35 pp. Presentation of the concept of "influscid" flow defined as the region where gradients of velocity, temperature, pressure, and species concentration are so small that transport processes related to

viscosity, thermal conductivity, thermal diffusion, pressure, and concentration diffusion may be conveniently neglected. The "fluscid" region is then the boundary layer adjacent to the body, where the aforementioned gradients are so large that coupled transport processes constitute the essential physical phenomena. The fundamental boundary layer equations, appropriate for the analysis of the interaction between a flowing multicomponent chemically reacting gas and a surface, are then formulated for a typical coordinate system.

NEGATIVE MAGNUS EFFECT. Sadatoshi Taneda. Kyushu U., Rep. Res. Inst. Appl. Mech., No. 20, 1957, pp. 123-128. Experimental investigation of the negative Magnus force occurring during the rotation of a sphere about a cross-flow axis in a uniform stream. It is found that this effect can be explained as a transition effect of the boundary layer from laminar to turbulent flow. Photographs of the actual flow pattern around a rotating sphere are taken by means of an aluminum-dust method, and the difference between the two flow patterns of ordinary Magnus effect and that of negative Magnus effect is given.

INVISCID FLOW FIELD AROUND A BLUNT BODY AT HYPERSONIC SPEEDS. I - THE STAGNATION POINT REGION. Ting Yi Li. Rensselaer Polytech. Inst. Dept. Aero. Eng. TR AE5706 [AD 136747], Sept. 7, 1957. 64 pp. 16 refs. Study of the inviscid hypersonic flow in the stagnation-point region on a blunt body of revolution, with particular emphasis on the determination of the effects of the body curvature. The flow field is assumed to be at thermodynamic equilibrium; the density variation within the shock layer is neglected; and the shock layer thickness is taken to be constant in the stagnation-point region. Geometrical considerations lead to the conclusion that the blunt nose can be treated as essentially spherical. The results of the investigation are compared to the simple theory of Li-Geiger and it is found that the major effects of the body curvature are (1) to increase the shock detachment distance over the theoretical values predicted by Li-Geiger, (2) to provide a pressure relief on the body surface as predicted in the Newtonian-plus-centrifugal force formula, (3) to increase the value of the nondimensional velocity gradient at the stagnation point over the value obtained by Li-Geiger, and (4) to modify the velocity distribution within the shock layer.

PRESSURE DISTRIBUTIONS AT TRANSONIC SPEEDS FOR PARABOLIC-ARC BODIES OF REVOLUTION HAVING FINENESS RATIOS OF 10, 12, AND 14. R. A. Taylor and J. B. McDevitt. US, NACA TN 4234, Mar., 1958. 80 pp. Experimental investigation on models tested at zero angle of attack through a Mach Number range from 0.80 to 1.20, and Reynolds Number variation from 23.4×10^6 to 28.6×10^6. Data for axial faces, body pressures, and field pressures with the models at zero angle of attack are presented. The measured drag data coefficients, adjusted to represent free-stream static pressure at the model base and the measured base drag are given. Tunnel-wall interference effects in general depend on model geometry, on the relative size of the model with respect to the tunnel size, and on the type of tunnel wall used. Interference-free data cannot be expected at transonic speeds unless the model size, relative to the tunnel size, is extremely small. A method for comparing the experimental results with slender-body concepts is obtained.

AN INVESTIGATION OF THE UNSTEADY FLOW PATTERN IN THE WAKE OF CYLINDERS AND SPHERES USING A HOT-WIRE PROBE. C. Cometta. Brown U., Div. Eng., TR WT-21 (AFOSR TN 57-760) [AD 136749], Oct., 1957. 31 pp. 14 refs. Study of the behavior of the Strouhal Number at and near the critical Reynolds Number at subsonic speeds. Above a Reynolds Number of Re = 200,000 and a cylinder diameter to channel width ratio of 0.23 there appear two simultaneous vortex streets. On the outside of the ordinary vortex street two layers containing oscillations of lower frequency are observed. The dependence of the Strouhal Number on Reynolds Number behind three-dimensional bodies is determined. For spheres of diameter greater than about 2 cm. there appears to be a critical Reynolds Number of 7,400 at which the Strouhal Number changes rapidly from one value to a very much different value.

SUPERSONIC FLOW AROUND QUASI-CONICAL BODIES, WITH APPLICATION TO WING-BODY INTERFERENCE. H. J. Stetter. USAF OSR TN 3 (TN 58-167) [AD 152194], 1958. 24 pp. Development of a theory for the computation of the linearized supersonic flow field around a quasi-conical body. The disturbance potential and its derivatives are gained from the boundary condition either by the use of characteristic functions or by reduction to the quasi-cylindrical problem. It is also demonstrated that not only the flow field around a slightly bumped or indented circular cone may be computed, but also the wing-body interference problem for a circular conical body with wings with supersonic leading edges may be solved.

SIMILITUDE OF HYPERSONIC FLOWS OVER THIN AND SLENDER BODIES - AN EXTENSION TO REAL GASES. H. K. Cheng. Cornell Aero. Lab. Rep. AD-1052-A-6 (AFOSR TN 58-87) [AD 148136], Feb., 1958. 19 pp. 12 refs. Analysis of the similitude in the hypersonic inviscid flow field over thin or slender bodies based on the governing equations and boundary conditions. When local thermal equilibrium prevails, i.e., when the properties of the gas are determined nearly by the thermodynamic properties corresponding to the local pressure and temperature, the parameter $M_\infty \tau$ of Tsien and Hayes remains the controlling parameter for the similar fields of hypersonic flows past thin or slender bodies. However, general correlation of similar flows of real gases is possible only between flows under the same free-stream atmosphere. Examples of correlation are given for flows of real gases over wedges.

EFFECT OF RADIATION ON SHOCK WAVE BEHAVIOR. R. E. Marshak. Phys. Fluids, Jan.-Feb., 1958, pp. 24-29. Presentation of the fundamental equations governing fluid dynamics including radiation, and derivation of the corresponding Rankine-Hugoniot conditions, for shock waves in the presence of radiation. Similarity solutions are obtained for the constant density and constant pressure cases. Some results are stated for the combined radiation-fluid dynamics corresponding to a power law dependence of the temperature on the time.

SHOCK WAVES OF LARGE AMPLITUDE IN AIR. Ia. B. Zel'dovich. (Zhurnal Exper. i Teoret. Fiz., May, 1957, pp. 1, 126-1, 135.) Sov. Phys. - JETP, Dec., 1957, pp. 919-927. 17 refs. Translation. Study of the state of air compressed by strong shock waves, taking dissociation and ionization into account. Approximate expressions are given for the density and temperature in this region. The radiation from the front of the shock is considered. With increasing shock-wave amplitude, the observed surface temperature passes through a maximun, owing to the formation of an opaque layer of air, preheated by radiation ahead of the front of the wave. A proof is given of the nonexistence of a continuous solution and of the unavoidability of discontinuities in the velocity, density, and temperature in a strong shock wave with radiant heat exchange. The wave structure is investigated in strongly-ionized gas with allowances for the slow energy transfer between the ions and the electrons.

TOCHNOE RESHENIE NELINEINOI ZADACHI O VZRYVE V GAZE PRI PEREMENNOI NACHAL'NOI PLOTNOSTI. V. P. Korobeinikov. AN SSSR Dokl., Dec. 21, 1957, pp. 947, 948. In Russian. Derivation of an exact solution for the nonlinear problem involving an explosion in a gas of variable initial density, generating spherical, cylindrical, or plane shock waves.

ON THE STRUCTURE OF THE FRONT OF STRONG SHOCK WAVES IN GASES. Iu. P. Raizer. (Zhurnal Exper. i Teoret. Fiz., June, 1957, pp. 1, 528-1, 535.) Sov. Phys. - JETP, Dec. 15, 1957, pp. 1, 242-1, 248. Translation. Investigation of the internal structure of a shock wave in air, taking into account radiant thermal conduction. Approximate solutions of the equations of the mode are found, and profiles of the hydrodynamic quatities, density, and radiation flux are constructed.

THE STRUCTURE OF SUPERSONIC FLOW. R. E. Meyer. Brown U., Div. Appl. Math. Rep. (AFOSR TN 58-52) [AD 148094], Jan., 1958. 15 pp. 13 refs. Discussion of the invariant properties in the large of wave fronts, branch lines, and limit lines in the steady two-dimensional, irrotational and homentropic flow of perfect gas.

NUMERICAL ANALYSIS OF INVISCID SUPERSONIC FLOWS, UTILIZING THE STREAMSURFACE CHARACTERISTICS METHOD. C. Cobb, H. G. Loos, and S. Manus. Propulsion Res. Corp. Rep. R-279 (AFOSR TN 58-105) [AD 152014], Jan., 1958. 31 pp. Programming of the stream-surface characteristics method for the IBM-650 digital computer. It is found that the isentropic supersonic flow between two close surfaces of arbitrary but regular shape, subject to proper boundary conditions, can be determined at a speed of about 1.78 minutes per point. It is concluded that the IBM 650 is somewhat too small for the problem, and that the present computation should be reprogrammed for a high-speed digital computer with a large storage capacity, such as the IBM-704.

STATISTICAL BEHAVIOR OF A REACTING MIXTURE IN ISOTROPIC TURBULENCE. Stanley Corrsin. Phys. Fluids, Jan.-Feb., 1958, pp. 42-47. 10 refs. ONR-supported deduction of equations for some statistical functions of the concentration of reactant made under the following restrictions: (a) isotropy in turbulent velocity and concentration fluctuation fields, (b) negligible effect of reaction on fluid motion, and (c) negligible effect of heat reaction on local reaction rate.

Internal Flow

THE EFFECT OF INLET CIRCUMFERENTIAL MALDISTRIBUTION ON AN AXIAL COMPRESSOR STAGE. R. C. Turner, J. Ritchie, and C. E. Moss. Gt. Brit., ARC R&M 3066, 1958. 16 pp. BIS, New York, $1.08. Description of tests on a single compressor stage with circumferentially nonuniform inlet conditions as a model of the first stage of a typical modern compressor. It is found that with a roughly rectangular inlet velocity distribution of amplitude $\pm$ 25% of the mean value, the surge flow instead of showing an expected increase is almost unchanged and is, in fact, slightly reduced. The efficiency falls greatly, with an accompanying small drop in temperature-rise coefficient. The velocity profile is distorted and its amplitude greatly decreased at the outlet of the stage.

BERECHNUNG DER REIBUNGSLOSEN STRÖMUNG FÜR EIN VORGEGEBENES EBENES SCHAUFELGITTER BEI HOHEN UNTERSCHALLGESCHWINDIGKEITEN. H. Schlichting and E. G. Feindt. Forschung Gebiete Ing., Ausg. A, No. 1, 1958, pp. 19-28. In German. Development of a simple approximate method, by means of the Prandtl-Glauert rule, for the frictionless compressible flow through a two-dimensional cascade as occurring at high subsonic speeds. The method is valid for cascades with arbitrary stagger angles, provided the blades are of moderate thickness and camber. The case of the compressible flow through a given cascade at any Mach Number is reduced during the calculation to a corresponding incompressible flow through a cascade having the same blades, arranged, however, with a smaller pitch ratio and a larger stagger angle. A comparison of several pressure distributions as calculated along the blade profile shows good agreement with results measured in a high-speed cascade wind tunnel.

THEORETICAL INVESTIGATION OF SUBSONIC OSCILLATORY BLADE-ROW AERODYNAMICS. Appendix A - EXPRESSION OF AERODYNAMIC INTEGRAL EQUATION IN CONVENTIONAL FORM. Appendix B - APPLICATION OF AERODYNAMIC INTEGRAL EQUATION TO INCOMPRESSIBLE FLOW. Appendix C - COMPUTATIONAL PROCEDURES. Frank Lane and Manfred Friedman. US, NACA TN 4136, Feb., 1958. 64 pp. 13 refs. Development of a method for calculating aerodynamic oscillatory lifts and moments experienced by cascades or compressor blade-rows in subsonic flow as well as to examine analytically the existence of the resonance phenomenon. The kernel function of the aerodynamic integral equation is effectively reduced by the Fourier transform; oscillatory lifts and moments are easily derivable without the necessity of inverting. The results of a specific set of computations are presented in order to prove the accuracy and feasibility of the method.

ON THE STABILITY OF VISCOUS FLOW IN A CURVED CHANNEL. W. H. Reid. Royal Soc. (London) Proc., Ser. A, Mar. 11, 1958, pp. 186-198. Analysis of viscous flow between two concentric cylinders due to a pressure gradient acting round the cylinders, considering the spacing between the cylinders as small compared to their radii. Two methods of approximate solution are described, both of which show that instability first sets in when the parameter $R\sqrt{(d/R_1)}$ attains a value of about 36 which is in close agreement with earlier results of Dean (1928). The pattern of motion which then occurs is of the familiar cellular type but with a marked asymmetry.

TURBULENT FLOW THROUGH POROUS RESISTANCES SLIGHTLY INCLINED TO THE FLOW DIRECTION. A. L. Loeffler, Jr., and Morris Perlmutter. US, NACA TN 4221, Feb., 1958. 29 pp. 11 refs. Analytical and experimental studies of the channel flow of air through a porous resistance inclined at an angle of $3\ 1/2^{\circ}$ to the axis of the channel with the air discharging into the atmosphere. The analytical study introduces the assumption of an incompressible flow with an unknown parameter β, defined as the fraction of the original momentum transferred to the fluid remaining in the channel by the fluid entering the porous resistance. The results indicate: (a) a uniform flow from the porous wall can be obtained by shaping the wall of an inclined-flow apparatus where the angle between the incoming flow and the porous wall is small; (b) the developed theory can be applied to predict the approximate wall shape for a uniform flow if the value of β is known; (c) values of β of 0 and 0.2 are obtained experimentally for the perforated plate and plate-cloth resistances, respectively; and (d) the uniform flow is attained at the expence of increased loss of total pressure.

EFFECT OF WALL COOLING ON INLET PARAMETERS OF A SCOOP OPERATING IN A TURBULENT BOUNDARY LAYER ON A FLAT OR CONICAL SURFACE FOR MACH NUMBERS 2 TO 10. Appendix A, B - DERIVATION OF INLET PERFORMANCE PARAMETERS FOR SCOOP OPERATING IN A TURBULENT BOUNDARY LAYER WITH WALL COOLING. Appendix C - CALCULATION OF ADIABATIC-TO-COOLED BOUNDARY -LAYER THICKNESS RATIO. Andrew Beke. US, NACA TN 4153, Mar., 1958. 21 pp. Calculation of the mass-flow, momentum, total-temperature, and total-pressure recovery ratios for a scoop inlet having a height equal to the boundary-layer thickness. Variations of the inlet parameters, for flat and conical surfaces, are presented for several wall-to-free-stream static-temperature ratios and for Mach Numbers from 2 to 10. For wall-to-free-stream static-temperature ratios of unity, mass flow and momentum are up to 50% higher than for an adiabatic flat plate or conical surface. Associated with these changes are a total-temperature decrease up to 6% and a small increase in total-pressure recovery.

ON THE DESIGN OF UNIFORM FLOW SUBSONIC NOZZLES. D. M. Rao. Aero. Soc. India J., Nov., 1957, pp. 51-55. Analysis based on one-dimensional flow and isentropic area-Mach Number relationship, which suggests a method of arriving at the boundary layer correction for taking into account all known and unknown secondary fluid dynamic effects which exist in noncircular ducts. Experimental values of the boundary layer displacement thickness growth rate, obtained from a simple test on a constant area nozzle, are used to calculate the height divergence of a two-dimensional nozzle for uniform flow in the subsonic range.

Stability & Control

THE INFLUENCE OF NON-STATIONARY DERIVATIVES ON THE SNAKING MOTION AT HIGH SUBSONIC SPEED. J. Yff. Netherlands, NLL TR F. 208, Nov. 23, 1957. 37 pp. 10 refs. Presentation of some lateral stability calculations with two degrees of freedom for flights at Mach Numbers 0.7 and 0.9, assuming small aspect ratios and taking into account compressibility effects. It is found that only the yawing moment coefficient due to sideslip ($C_{n_{\dot{\beta}}}$) has a small influence on the damping in yaw, the influence of the other nonstationary derivatives being negligible. Whether the introduction of $C_{n_{\dot{\beta}}}$ causes a decrease or an increase of the damping in yaw depends mainly on the aspect ratio of the vertical tail, but, for nearly all practical tail designs, an increase of the damping in yaw will result. Furthermore, it is found that the theoretical nonstationary stability derivatives for vertical tails are practically independent of the reduced frequency.

Wings & Airfoils

NOTE ON SWEPT WING PLANFORMS WHICH CORRESPOND TO THE SAME TWO-DIMENSIONAL POTENTIAL PROBLEM FOR FINDING MINIMUM DRAG AS THE ELLIPTICAL PLANFORM. B. J. Beane. Douglas Rep. SM-22986, Nov., 1957. 11

pp. Analysis in which some swept wing plan forms are found, corresponding to the same two-dimensional potential problem for finding minimum drag as the elliptical plan form. It follows that, for fixed total lift, the theoretical minimum value of wave plus vortex drag for the swept wings is the same as for the corresponding elliptic wings. In most cases the areas of the swept wings are found to be less than the areas of the corresponding elliptic wings.

NEUSTANOVIVSHIESIA DVIZHENIIA KRYLA KONECHNOGO RAZMAKHA V SZHIMAEMOI SREDE. E. A. Krasil'shchikova. AN SSSR Dokl., Dec. 11, 1957, pp. 777-780. In Russian. Study of the spatial motion of a compressible fluid generated by the nonstationary motion of a finite-span wing in a liquid at rest. The study of motion covers conditions under which only small perturbations are produced. The problem is linearized and the well known assumptions of the thin-wing theory are introduced. The solution is constructed along the fixed coordinate axes, x0yz, defining the spatial motion of the wing.

DRAG DUE TO LIFT AT SUPERSONIC SPEEDS FOR A SWEPT WING COMPOSED OF TWO OPPOSITELY-YAWED ELLIPTICAL PLANFORMS. B. M. Ryan. Douglas Rep. SM-22987, Nov., 1957. 34 pp. Analysis to determine the drag of two coplanar elliptical plan forms, and comparison with the drag of the two noninterfering co-planar components. It is found that interference drag, which at small overlap is negative and thus favorable, can become positive or unfavorable as the overlap is increased. However, even in this case the yawed wings still have a drag advantage over the unyawed wings. Further reduction in the drag of the interfering yawed wing combination could be effected by the addition of favorably interfering lift distributions, since the distributions employed in the calculations were nonoptimum for the combination of two wings.

THE WAVE DRAG OF WING-QUASI-CYLINDER COMBINATIONS AT ZERO INCIDENCE. Appendix - CONVERGENCE OF THE DRAG FORMULAE. L. E. Fraenkel. Aero. Quart., Feb., 1958, pp. 55-70. 12 refs. Derivation of three drag formulas to supplement G. N. Ward's "area-transfer rule." The first involves the Laplace transforms of functions representing the strengths of the sources and multi-sources; the difficult problem of inverting these transforms is thereby avoided. The second involves these strength functions themselves, and is in the form of a series of double integrals of the von Kármán type. The third involves functions describing the geometry of a hypothetical quasi-cylinder which has the same drag as the whole configuration in question. The convergence of these formulas is established. The results are then used to make an order-of-magnitude analysis for wing-slender-body combinations. A large number of drag terms are seen to be negligible when the ratio of body radius to wing chord is small, and the dominant terms of smooth bodies are those appearing in Ward's drag formula.

AEROELASTICITY

FLUTTER OF LOW ASPECT-RATIO WINGS. I - CALCULATION OF PRESSURE DISTRIBUTIONS FOR OSCILLATING WINGS OF ARBITRARY PLANFORM IN SUBSONIC FLOW BY THE KERNEL-FUNCTION METHOD. Pao-Tan Hsu. MIT ASRL TR 64-1, Oct., 1957. 74 pp. 16 refs. Derivation of an improved method for the calculation of pressure distribution on an oscillating wing of arbitrary plan form in subsonic flow, based on a numerical solution of the pressure-downwash integral equation. A continuous pressure distribution over the plan form, which satisfies the boundary conditions at the edges, is assumed. The numerical integration is accomplished by taking a summation of the point values of the integrand at a set of special integration stations. Several numerical examples are presented for the two- and three-dimensional cases. Results of the total lift and total moment on a 45° constant chord swept wing of aspect ratio two at M=0, k=4, and M=0.8, k=0.4 are also obtained. The result for M=0, k=0.4 case is compared with the incompressible experimental result and shows reasonable agreement.

FLUTTER OF LOW-ASPECT-RATIO WINGS. II - AEROELASTIC MODEL DESIGN AND TESTING. M. M. Chen. MIT ASRL TR 64-2, Oct., 1957. 105 pp. 16 refs. Study indicating that the design of a doubly-flexible model of a low-aspect-ratio wing is straightforward and successful when based directly on stiffness distributions and the analogy to an aelotropic plate. An improved technique of designing beam-like models for influence coefficient data is also presented. Influence coefficients, mass distribution, and flutter data are given for a previously tested model of the XF-92A delta wing with elevon. The data are sufficient to permit flutter analyses to be carried out on the model.

ON DAMPED FREE VIBRATION WITH PARTICULAR REFERENCE TO SYSTEMS HAVING NEARLY-EQUAL NATURAL FREQUENCIES. R. E. D. Bishop and D. C. Johnson. Aero. Quart., Feb., 1958, pp. 71-95. Derivation of an approximate theory for small damping using an analytical method which shows the nature of the entrainment of the principal modes. The results are found to confirm those of Southwell (who uses a physical argument) and are illustrated by an example. The approximate theory is shown to need modification when there are two nearly-equal natural frequencies and the appropriate corrections are found. The analysis is made somewhat complicated by the existence of two criteria of "smallness" instead of one; these are the difference between the close natural frequencies and the amount of damping.

AIRPLANE DESIGN

OPEN CYCLE REFRIGERATION. E. J. Gabbay. Aircraft Eng., Mar., 1958, pp. 64-71. Review of

the basic theory of the bootstrap refrigeration and consideration of the main aspects of design and system performance. The bootstrap scheme of refrigeration is an open cycle system resembling a turbojet engine in its mode of operation, but the overall heat energy changes occur in a reversed sense.

FUELS & LUBRICANTS

Propellants

SOME EFFECTS OF OXIDIZER CONCENTRATION AND PARTICLE SIZE ON RESONANCE BURNING OF COMPOSITE SOLID PROPELLANTS. Leon Green, Jr. (ARS 12th Annual Meeting, New York, Dec. 2-5, 1957.) Jet Propulsion, Mar., 1958, pp. 159-164. OSR-sponsored comparison of four composite propellant formulations tested at 170°F. in internal-burning tubular charges, partially supporting the widely held belief that the tendency toward irregular reaction increases as the energy content of the propellant is raised. However, the highest energy formulation showed a smooth reaction, apparently as a result of a burning rate lower than anticipated on the basis of Crawford bomb measurements. The results suggest that the rate of energy release affords a better measure of the relative stability behavior of various formulations than burning rate or energy content.

ICE FORMATION & PREVENTION

CORRELATIONS AMONG ICE MEASUREMENTS, IMPINGEMENT RATES, ICING CONDITIONS, AND DRAG COEFFICIENTS FOR UNSWEPT NACA 65A004 AIRFOIL. V. H. Gray. US, NACA TN 4151, Feb., 1958. 45 pp. 11 refs. Establishment of the correlation by measuring the ice heights and angles from a variety of ice formations which are carefully photographed, cross-sectioned, and weighed. It is shown that ice weights increase at a constant rate with icing time in a rime icing condition and at progressively increasing rates in glaze icing conditions. Good agreement is obtained for the initial rates of ice collection with values predicted from droplet impingement data which, in turn, agree with previous theoretical calculations for angles of attack of 4° or less. Disagreement at higher angles of attack is attributed to flow separation from the upper surface of the experimental airfoil model.

METEOROLOGY

FREE-AIR TURBULENCE. A. D. Anderson. J. Meteorology, Dec., 1957, pp. 477-494. 14 refs. Analysis of 1,877 measurements made by a gustsonde in order to determine the relation between turbulence and meteorological parameters. A theory derived from the above-normal turbulence range has the following elements: (1) transitions occur in free-air turbulence flow, similar to transitions occurring in incompressible fluid flow; (2) transitions occur at certain values of Richardson's Number R; (3) the vertical wind shear term is the most important parameter in R governing the turbulent flow.

MISSILES

ASUPRA MIŞCĂRII DE CĂDERE A RACHETELOR. N. Tipei. Stud. Cerc. Mec. Aplic., No. 3, 1957, pp. 619-628. In Rumanian, with summaries in Russian and French. Study of the motion of a rocket during its descent in vacuum with time-dependent traction, taking into account the variation of the gravitational field with altitude. The complete solution is obtained by means of power series of the ratio of velocity components, or in a closed form, in the case of zero-traction. For the descent through air it is shown that the exponential density law can be extended, in accordance with the new data on the physical characteristics of the atmosphere, to very high altitudes. By using a transformation of the equations of motion in the hodograph plane, the solutions for the problem are obtained on the assumption that the drag coefficient varies with Mach Number and that it is constant. It is concluded that, in general, the calculations are simpler than those currently in use and allow a higher degree of accuracy.

OB URAVNENIIAKH ZADACHI OPREDELENIIA MESTOPOLOZHENIIA DVIZHUSHCHEGOSIA OB'EKTA POSREDSTVOM GIROSKOPOV I IZMERITELEI USKORENII. A. Iu. Ishlinskii. Prikl. Mat. i Mekh., Nov.-Dec., 1957, pp. 725-739. In Russian. Analysis of the theory covering a possible version of the problem pertaining to the autonomous determination (i.e., without the use of external orientation) of the location of a moving object, under the assumption that no errors were introduced during the calculation. The following cases are included: displacement of an object along the arc of a large circle (a certain nonrotating sphere S) whose center coincides with the center of the earth; displacement of an object whose center moves arbitrarily along the earth's sphere; small displacements of a stabilized platform under the assumption that its plane was not initially located directly over the horizon and that the conditions pertaining to the selection of parameter values m_1 and m_2 introduced a small error. Also includes other methods of calculation leading to the same result.

AN ANALYSIS OF THE OPTIMIZATION OF A BEAM RIDER MISSILE SYSTEM. Marvin Shinbrot and G. C. Carpenter. US, NACA TN 4145, Mar., 1958. 33 pp. 13 refs. Derivation of a transfer function for a beam-rider missile guidance system which is optimum when the target moves in a nonstationary way. The effects of acceleration are considered, and a discussion of the miss as a function of the various determining parameters is included. Also presented is a form of design chart which allows the immediate determination of the optimum under any set of target-missile conditions.

GUIDANCE AND CONTROL PROBLEMS IN THE AIR FORCE BALLISTIC MISSILE PROGRAM. I. J. C. Fletcher. Aero / Space Eng., May, 1958.

pp. 50-54. Discussion of the principal problems encountered in guidance analysis, control systems, and radio guidance. The function of a guidance and control system is defined as the establishment of an appropriate flight path during the boost phase of the trajectory, and to terminate thrust at an appropriate velocity and position in space so that the resultant ballistic trajectory intersects the earth at the target point. The purpose of the measurement system, computer, and control system is outlined. The radio and the inertial measurement systems are discussed as to the advantages of each over the other, and the combination of the two systems is also included. Control system design considers problems in fuel sloshing, damping, prevention of tumbling, and obtaining sufficient actuator speed. Tropospheric and ionospheric scattering problems are reviewed in terms of their effect on phase difference measurements for radio guidance. The effects of radio propagation through the ionized exhaust area are also considered.

HYPERSONIC AERODYNAMIC FACTORS IN PERFORMANCE, GUIDANCE, AND CONTROL. W. H. Dorrance. Aero / Space Eng., May, 1958, pp. 30-33, 43. 11 refs. Study of the possible effects of dissociation and ionization behind strong shock waves on stability and guidance of hypersonic vehicles. The requirements for dynamic and static stability for certain classes of hypervelocity atmospheric entry bodies are described. It is concluded that stability and performance coefficients may be difficult to determine because of the uncertain state of the knowledge on the behavior of high-temperature air. A serious communication problem may arise, owing to the high electron density which may exist in the hot gas surrounding a hypersonic vehicle. Hypersonic atmospheric entry vehicles may require automatic control during descent to achieve pilot comfort, guidance, and fusing system accuracy. Thermal protection systems for hypervelocity vehicles may not be well suited to radome and electromagnetic wave propagation.

A GENERALIZED OPTIMIZATION PROCEDURE FOR N-STAGED MISSILES. Leon Weisbord. Jet Propulsion, Mar., 1958, pp. 164-167. Presentation of a simple method for determining the optimum weight distribution for a staged rocket with different structural factors and propellant specific impulses in each stage. The method can be used in a first design estimate to determine the weight breakdown within each stage.

NAVIGATION

CROSS COUPLING IN INERTIAL NAVIGATION SYSTEMS. R. E. Wilson and J. B. Lewis. Aero / Space Eng., May, 1958, pp. 60-65, 80. Study showing how the navigation of hypersonic aircraft over a nearly spherical earth involves significant interaction or coupling occuring between lateral (cross range) errors and azimuth errors, and also between longitudinal (range) errors and vertical channel (velocity and altitude) errors. It is shown that the major cause of both types of coupling is the relatively high angular velocity of the aircraft about the center of the earth. Assuming essentially constant altitude, it is found that the normal load factor, defined here as the ratio of total vertical acceleration to sea-level gravity, is sufficient to describe the coupling parameters completely. Typical simple expressions are given for estimating distance error responses in terms of the normal load factor in the case of a constant velocity flight.

PHYSICS

Special Issue: IGY INSTRUCTION MANUAL. IV - SOLAR ACTIVITY. V - NUCLEAR RADIATION; RADIOACTIVE FALL-OUT DATA AND THEIR INTERPRETATION. VI - RADIATION INSTRUMENTS AND MEASUREMENTS. IGY Ann., Vol. V, pts. IV, V, VI, 1958. 466 pp. 476 refs. IV - General plan for the centralization of solar data during the geophysical year and instruction manuals for the different subjects referred to different centers. V - The use of radioactive tracers in meteorology, vertical distribution of radioactivity in the atmosphere, radioactivity as a tracer of air motions in the atmosphere, and summaries of other scientific papers. VI - Solar radiation, total (short-wave) radiation of sun and sky, long-wave (terrestrial) radiation and the radiation balance, and reduction of records and presentation of data.

THE STRUCTURE OF SHOCK WAVES IN A PLASMA. V. D. Shafranov. (Zhurnal Exper. i Teoret. Fiz., 1957, p. 1,453.) Sov. Phys. - JETP, Dec. 15, 1957, pp. 1,183-1,188. Translation. Investigation of shock waves, taking into account the difference between the ion and electron temperatures. The following cases are considered: (a) nonstationary shock wave in which the exchange of energy between electrons and ions may be neglected; (b) stationary shock wave; (c) stationary shock wave in a strong magnetic field.

TECHNICAL REPORT OF RESEARCH PERFORMED BETWEEN OCT. 1, 1956 AND SEPT. 30, 1957. I - EFFECTS OF PROTON CORRELATIONS ON THE SCATTERING OF HIGH-ENERGY ELECTRONS FROM NUCLEI. L. I. Schiff. II - THEORY OF HIGH-ENERGY POTENTIAL SCATTERING. D. S. Saxon and L. I. Schiff. III - ON THE VALIDITY OF LEVINSON'S THEOREM FOR NON LOCAL INTERACTIONS. A. Martin. Ecole Normale Supérieure, Lab. Phys. TR (AFEOARDC TN 57-745 [AD 136732], 1958. 58 pp. 27 refs. I - Development of a method to analyze proton correlations inside nuclei from high energy electron scattering on medium-heavy as well as heavy nuclei. II - Presentation of a formula for scattering at high energy (or short wavelengths) which is valid at all angles. III - Comparison of the number of eigenstates of a non local Hamiltonian to the number of free eigenstates by the introduction of an artificial boundary condition on the one-dimensional S wave function.

NUCLEON - NUCLEON SCATTERING AT HIGH ENERGY. M. Gourdin. Ecole Normale Supérieu-

re, Lab. Phys. TN 7 (AFEOARDC TN 57-683) [AD 136678], 1958. 33 pp. 30 refs. Explanation of the nucleon-nucleon scattering and polarization experiments using a completely covariant formulation for two body systems - the Bethe and Salpeter equation - in order to take into account relativistic corrections. The partial-waves method is generalized to a four-dimensional euclidean problem using an analytic continuation of the scattering amplitude for the imaginary values of relative time or energy. It is shown that, in the simplified case of spinless particles (Klein-Gordon particles), the physical phase shifts corresponding to a given value of the orbital angular momentum are easily obtained. For the more realistic case of spin 1/2 particles (Dirac particles) it is possible to calculate the differential cross section. Explicit solutions are obtained with an approximate method of resolution for the integral equations.

POWER PLANTS

SULLA POSSIBILITA DI FUNZIONAMENTO DI UN "MOTORE AD ONDE" A TUBI RADIALI RUOTANTI. Dino Dini. L'Aerotecnica, Oct., 1957, pp. 257-272. In Italian. Analysis of the operational possibilities of a "wave engine" operating directly on the cavity of each single radial rotating tube of a multiple tube rotor. The working principle is based on the unsteady motion due to the pressure waves occurring on the fluid after each combustion, owing to the intermittent opening of the tube ends. The influence of the combustion pressure and of the fuel-air mixture ratio on the specific impulse is investigated using wave diagrams and particular solutions of the differential equations of the approximate one-dimensional theory. The adjustment of the pulsating cycle frequency to some peripheral rotor velocities is also considered.

Jet & Turbine

PROPULSION SUPERSONIQUE PAR REACTEURS. Maurice Roy. France, ONERA NT 42, 1957. 38 pp. 10 refs. In French. Investigation of the performance of supersonic jet propulsion systems using the surrounding air by means of an analysis of the governing fundamental formulas. The overall power plant characteristics and the operation of the combustion chamber, the air intakes, and the ejection nozzles are studied in detail. The operation of jet propulsion systems with or without afterburning and of the ram-jet are evaluated, as well as their association or combination.

ÜBER DIE FLAMMENSTABILITAT AN BRENNERN VON FLUGSTRAHLTRIEBWERKEN. Th. Seifferlein. Forschung Gebiete Ing., Ausg. A, No. 1, 1958, pp. 15-18. In German. Derivation of a general stability condition for the steady operation of flames behind flame holders in a jet engine from aerodynamic, thermodynamic, and reaction-kinetic considerations, based on the relationship between the necessary ignition energy and the available part of the chemically bound energy in the fuel. This stability condition can also be interpreted in diagram form.

ANALOGUE FOR HIGH-INTENSITY STEADY-FLOW COMBUSTION PHENOMENA. D. B. Spalding. (IME Gen. Meeting, London, Jan. 11, 1957.) IME Proc., No. 10, 1957, pp. 383-396; Discussion, pp. 396-402; Communications, pp. 403-407; Author's Reply, pp. 408-412. 19 refs. Development of an air-flow model in which the chemical reaction is simulated by electric heaters distributed through the chamber. External controls regulate the heat input in accordance with local temperatures and the properties of the fuel which is to be simulated. Good agreement is found between predicted blow-out velocities of baffle-stabilized flames and experiments reported by other workers. Tests are also reported on two-dimensional combustion chamber designs for burning premixed fuel and air, the efficiency, space utilization, and pressure-drop performance being compared. It is shown by example that separate injection of fuel to the combustion chamber greatly reduces the blow-out velocity and space utilization, but increases combustion efficiency and the range of fuel-air ratios over which a flame can be maintained.

ANALYSIS OF STRESSES AND DEFLECTIONS IN A DISK SUBJECTED TO GYROSCOPIC FORCES. Appendix A, B - DERIVATION OF DIFFERENTIAL EQUATION FOR DEFLECTIONS OF VARIABLE-THICKNESS DISK SUBJECTED TO GYROSCOPIC LOADING. Appendix C - BOUNDARY-CONDITION EQUATIONS. Appendix D - FINITE-DIFFERENCE EQUATIONS. M. H. Hirschberg and A. Mendelson. US, NACA TN 4218, Mar., 1958. 37 pp. Derivation of the differential equation governing the deflection by considering the gyroscopic and centrifugal forces acting on a disc of variable thickness. Such forces occur on jet-engine compressor and turbine discs whenever the aircraft changes direction either in the air or on the ground. A finite-difference solution of this differential equation is obtained for a constant-thickness disc rotating about its center at a constant angular velocity. Results are presented in dimensionless form suitable for design purposes, and the method for solving the problem of a disc of variable thickness with a temperature gradient is also described

INVESTIGATIONS ON AN EXPERIMENTAL AIR COOLED TURBINE. III - THE EFFECTS OF COOLING ON THE OVERALL TURBINE AERODYNAMIC PERFORMANCE AND INITIAL OPERATION AT AN INLET GAS TEMPERATURE OF 1,400°K. Appendix I, II - ROTOR BLADE PUMPING LOSSES. D. E. Fray and N. E. Waldren. Gt. Brit., NGTE Rep. R.219, Jan., 1958. 28 pp. Study of changes in efficiency arising from the discharge of cooling air into the main gas stream from the tips of the nozzle and rotor blades, and from the sheet metal liners in the turbine inlet section. Endurance tests are made at high temperatures to examine the operating characteris-

tics and mechanical reliability of the turbine. It is concluded that a reduction in the nozzle blade tip clearance can increase the turbine efficiency by 5%. The discharge of cooling air into the main gas stream creates variations in the turbine stage aerodynamic efficiency. An increase in the turbine inlet gas temperature to 1,400°K. reduces the cooling effectiveness of the rotor blades by approximately 5% below that recorded at 1,000°K. A 2% loss of efficiency with the design quantities of cooling air applied is recorded.

COMPRESSOR-TURBINE MATCHING OF TWO-SPOOL TURBO-PROPS. A. W. Morley. Aero. Quart., Feb., 1958, pp. 17-33. Analysis considering the problem of the best division of pressure ratio between the two spools, using simplified expressions for component characteristics. It is found that a unique position of a low-pressure compressor operating line is obtained when the high-pressure operating line is vertical. This arrangement requires a low pressure ratio on the high pressure spool and gives an engine whose power is sensitive to air intake temperature changes, so that the high pressure rotor tends to overspeed at sea level and surge at high altitude.

A REVIEW OF THE PERFORMANCE OF EXHAUST SYSTEMS FOR GAS-TURBINE AERO-ENGINES. P. F. Ashwood. (IME Gen. Meeting, London, Nov. 2, 1956.) IME Proc., No. 3, 1957, pp. 129-144; Discussion, pp. 144-154; Author's Reply, pp. 155-158. 22 refs. Evaluation of the factors influencing exhaust system design, including the effects of the type of engine installation and the use of reheat. The influence of ducting losses on the thrust are then considered in terms of the effect on the performance of a typical turbo-jet engine. Turbine exhaust diffuser analysis is concerned with the effects of the diffuser area ratio and wall shape, and with the effects of inlet swirl. This has been extended by an investigation of the influence of the bullet support struts on the performance of an engine. The results of tests on a series of convergent-divergent nozzes up to a pressure ratio of nine are given, and the effects of design pressure ratio and divergence angle are illustrated. A one-dimensional theoretical treatment is used to show the relationship between the nondimensional and specific thrusts and the applied pressure ratio. The test results are then analyzed in terms of these thrust parameters and their related coefficients.

Rocket

THE OPTIMIZATION OF NOZZLE AREA RATIO FOR ROCKETS OPERATING IN A VACUUM. M. Goldsmith. Jet Propulsion, Mar., 1958, pp. 170-172. Analysis to determine the correct choice of nozzle area for the case when the ambient pressure may be neglected. Under such conditions, specific impulse of the propellant increases monotonically with increasing area ratio, but the increased weight of larger nozzles degrades performance. A linearized analytical approach to this problem is presented along with design charts.

AN ANALYSIS OF FUEL-OXIDANT MIXING IN SCREAMING COMBUSTORS. W. R. Mickelsen. Jet Propulsion, Mar., 1958, pp. 172-177. Study of vapor fuel-oxidant mixing for standing transverse acoustic fields simulating those found in screeching or screaming combustors. The additional mixing due to the acoustic field is shown to be a function of sound intensity, oscillation frequency, and stream velocity. The effects of these parameters are shown graphically for a realistic range of combustor conditions. The fuel oxidant ratio at various combustor stations is shown to have a cyclic fluctuation which is in phase with the pressure fluctuations.

SPACE TRAVEL

O METODE ISSLEDOVANIIA IONOSFERY S POMOSHCHIIU ISKUSSTVENNOGO SPUTNIKA ZEMLI. Ia. L. Al'pert. Uspekhi Fiz. Nauk, Jan., 1958, pp. 3-14. In Russian. Evaluation of methods for the investigation of the ionosphere by means of the artificial earth satellite. Includes discussion of the satellite orbit and velocity, the effect of ionospheric turbulence and ionization on measured data, and analysis of the results of measurements and their accuracy.

ESCAPE FROM A CIRCULAR ORBIT USING TANGENTIAL THRUST. D. J. Benney. Jet Propulsion, Mar., 1958, pp. 167-169. Analysis considering the space ship to be in a circular orbit when the motors are switched on, and the thrust is taken as tangential to the direction of motion at each instant. It is shown that a tangential thrust should be a close approximation to the optimal escape program. The mass ratio is calculated using the radius vector-length of path equation. The results are compared with those found by Tsien for the circumferential thrust. It is found that the tangential thrust program leads to a slightly smaller value for the mass ratio.

STRUCTURES

Bars & Rods

EXPERIMENTAL STUDIES ON FATIGUE CRACK PROPAGATION IN TORSION. Jan Hult. KTH Trans. 119, 1958. 46 pp. 35 refs. Extension of a previous theory on fatigue crack initiation and growth in torsion to the case of crack growth from a rounded vee-shaped notch. Crack propagation on reversedly twisted aluminum bars is studied experimentally, and crack lengths are measured during tests with a special ultrasonic method. Results are in general agreement with the theoretical predictions as regards the initiation and incipient crack growth. A deceleration of the crack growth not predicted by the theory is found to follow the initial state, and possible reasons for this deceleration are discussed. Size effect and cumulative damage in fatigue are investigated in relation to the presented theory.

Beams & Columns

TRANSIENT HEATING EFFECTS ON THE BENDING STRENGTH OF INTEGRAL ALUMINUM-ALLOY BOX BEAMS. R. A. Pride and J. B. Hall, Jr. US, NACA TN 4205, Mar., 1958. 38 pp. 11 refs. Determination of the interaction effects of external loading and rapid nonuniform and uniform heating on both buckling and the compressive failure of box beams. Equations for buckling and maximum bending strength are derived, and the calculated results are compared with the experimental data. A marked reduction in buckling strength is observed as a result of thermal stress. At failure, the results of all tests correlate well with those calculated by a compression maximum-strength theory based only on appropriate material properties. This correlation indicates that thermal stress effects which influence local buckling apprear alleviated at maximum load.

Cylinders & Shells

STATIC STRENGTH TESTS ON B/2 "JINDIVIK" REAR FUSELAGES OF RIVETED AND ADHESIVE BONDED CONSTRUCTION. Appendix I - VERTICAL STIFFNESS OF RIVETED AND ADHESIVE BONDED FUSELAGES. Appendix II - TORSIONAL STIFFNESS OF RIVETED FUSELAGE. Appendix III - TEST DETAILS--LOADING TO FAILURE OF ADHESIVE BONDED FUSELAGE. R. P. Brown, N. B. Joyce, I. S. Milligan, and C. A. Patching. Australia, ARL Note SM. 238, Jan., 1957. 42 pp. Experimental investigation which revealed in the riveted fuselage the necessity for an additional stiffening ring and the closing of the open section at the tailplane attachment. Both fuselages were loaded to failure for the lateral gust - 20° flap case. Failure occurred at 114% and 137% of the design failing load for the riveted and adhesive bonded construction, respectively. The vertical bending and torsional stiffness were found to exceed the minima as specified in RAF-RN design requirements.

THE ELASTICITY SOLUTION OF A LONG CIRCULAR CYLINDRICAL SHELL SUBJECTED TO A UNIFORM CIRCUMFERENTIAL RADIAL LINE LOAD. J. M. Klosner and F. V. Pohle. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 416, July, 1957. 50 pp. 11 refs. Application of the three-dimensional equations of elasticity to solve the problem of a long circular cylindrical shell. The elasticity solution is then compared with the Flügge and Timoshenko shell theory solutions for the case $b/a = 0.9$, $\nu = 0.3$.

DISCONTINUOUS BOUNDARY CONDITIONS AND LINEAR SUPPORTS IN STATICAL PROBLEMS OF CYLINDRICAL SHELLS. Zbigniew Olesiak. Arch. Mech. Stosowanej, No. 5, 1957, pp. 549-563. Theoretical investigation of a cylindrical radially loaded shell clamped at some segments, the remaining being simply supported. The problem of a cylindrical shell with simple linear supports inside the region and simply supported or clamped by segments along the periphery is also discussed. Using the principle of superposition these problems are reduced to systems of Fredholm's integral equations of the first kind. In addition, a method for solving the problem of a shell with clamped or simply supported edges without the use of integral equations is proposed, based on the assumption that the clamping moment is a form of a Fourier trigonometric series.

ASYMPTOTIC SOLUTIONS OF TOROIDAL SHELL PROBLEMS. R. A. Clark. Quart. Appl. Math., Apr., 1958, pp. 47-60. 11 refs. OOR-ONR-sponsored analysis of a method of asymptotic integration, developed previously for a nonhomogeneous differential equation involved in problems of thin elastic toroidal shells, showing how it can be refined and how the approximate solutions previously obtained can be generalized and extended. It is shown that previous solutions are the leading terms of an asymptotic expansion in inverse powers of a large parameter. Higher-order terms or corrections of two different types are obtained for toroidal shells of circular cross section and uniform thickness. Some of the results are found by specializing solutions derived first for toroidal shells of arbitrary cross section and possibly varying thickness, assuming only that the shell has a plane of symmetry perpendicular to the axis of revolution.

Elasticity & Plasticity

MODIFIED TRESCA'S YIELD CONDITION AND ASSOCIATED FLOW RULES FOR ANISOTROPIC MATERIALS AND APPLICATIONS. L. W. Hu. Franklin Inst. J., Mar., 1958, pp. 187-204. 15 refs. OOR-sponsored analysis to illustrate the applicability of the modified Tresca's yield criterion and associated rules to problems having known solutions for isotropic cases. The results obtained indicate that the anisotropy of a plastically deformed body may affect its stress distribution as well as its mode of deformation even though the parameter of anisotropy may not appear in the flow rules. The effects of anisotropy on the plastic flow are dependent on the degree of anisotropy of the strained body.

Plates

ON LIMIT ANALYSIS OF PLATES. Walter Schumann. Quart. Appl. Math., Apr., 1958, pp. 61-71. 10 refs. Army-sponsored study of bending in thin perfectly plastic plates of arbitrary shape under transverse load. The basic equations have been developed for a plate of a material obeying Tresca's yield criterion. The different types of plastic regimes that can arise are discussed as well as the discontinuities that can arise in the moment field. The technique of limit analysis is applied to determine the limit load for a concentrated force. The collapse load for such a force is found to be 2π times the yield.

EXPERIMENTAL INVESTIGATION OF CLAMPED CIRCULAR PLATES SUBJECTED TO RAPID CREEP. Burton Erickson, S. A. Patel, and N. J. Hoff. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 411 (AFOSR TN 58-51) [AD 148093], July, 1957. 10 pp. Experiments with 21 clamped circular plates tested at elevated temperatures and constant uniform lateral pressure. The plates were 12 in. in diameter and made of 5052-0 aluminum alloy sheet; the sheet thickness of 0.032, 0.040, 0.051, and 0.064 was used. The lateral deflection of the center of the plate was measured in each test and the curves showing the change in deflection with time are presented.

ON ELASTIC PLATES OF VARIABLE THICKNESS. F. Essenburg and P. M. Naghdi. U. Mich. Eng. Res. Inst. TN 2500-1-T (AFOSR TN 57-618) [AD 136607], Oct., 1957. 13 pp. 12 refs. Derivation of suitable stress-strain relations for elastic isotropic plates of variable thickness which include the effects of transverse shear deformation and normal stress, as well as the variation in thickness. The significance of the results is examined, using as examples the torsion of plates whose thickness tends to gives rise to equilateral triangular and elliptic cross sections. These examples show an exact agreement for the stress distribution with the corresponding results of Saint Venant's theory of torsion.

ON THE BOUNDS OF THE CRITICAL LOAD OF A CLAMPED PLATE IN COMPRESSION. R. K. Kaul and S. G. Tewari. Aero. Soc. India J., Nov., 1957, pp. 56-59. (Also in J. Appl. Mech., Mar., 1958, pp. 52-56.) Application of Temple's generalization of Kato's theorem, for the determination of close lower bounds, to the fundamental frequency of oscillation of a clamped square plate subjected to uniform biaxial edge tension. The method depends upon the solution of an auxiliary problem governing the residual mode shape; in the present case it is determined by the Ritz variational method. It is shown that, by adopting even the simplest tentative mode shape, the principle leads to values much closer to accurate values than the upper bound derived by the use of Rayleigh's stationary principle.

Sandwich Structures

BENDING AND BUCKLING OF SANDWICH BEAMS, PLATES AND SHELLS. Masatsugu Kuranishi and Hiroshi Nagao. Nihon U., Res. Inst. Tech. J., Sept., 1957, pp. 16-33. 13 refs. In Japanese. Development of a bending theory for sandwich beams, plates, and shells under the assumptions that the faces are very thin and the cores take only shearing stress, while the thickness remains unchanged. The buckling loads are then computed for sandwich columns under axial compression, the sandwich plates under one-directional compression and shear, and the cylindrical sandwich shells under axial compression and torsion. For practical applications, the buckling in the plastic range is also considered and the weight-strength ratios are discussed.

Testing

PHOTO-THERMOELASTIC INVESTIGATION OF I-BEAMS. Herbert Tramposch and George Gerard. NYU Coll. Eng. Res. Div. TR SM 58-1 (AFOSR TN 58-70) [AD 148113], Jan., 1958. 26 pp. Further investigation of the photo-thermoelastic technique by extension of methods developed for simple rectangular beams to more complex shapes representative of an airframe. Particular attention is given to transient thermal stresses in I-beams produced by a temperature differential suddenly applied at top and bottom surfaces of the beam. The test data are correlated with theory using the material properties of the model, previously obtained by calibration, and the measured temperature distribution over the cross section. Includes detailed description of the instrumentation developed for the rapid measurement of transient temperatures and a graphical representation of the maximum stresses in nondimensional form.

Thermal Stress

LA DETERMINATION NUMERIQUE DES TEMPERATURES TRANSITOIRES DANS LES AILES. G. Lehr. Docaéro, Jan., 1958, pp. 3-14. In French. Numerical determination of transient temperatures in aircraft wings. Derivation of equations covering heat-conduction and accumulation laws; Newton law for the thermal transfer over a surface; and some special cases of heat transfer. Also derivation of equations by means of finite differences of the thermal flux within the body; thermal transfer at the boundaries; the case of an athermanous surface; the case of heat transfer by convection transverse to the main thermal flux; and step variations of the transverse section of the conducting body. Numerical applications include: the case of a semiinfinite plate with an instantaneous temperature change at the surface; a finite-thickness plate with convective heat transfer to both surfaces through a medium of constant temperature; and temperature distribution in the web of the wing spar and in the skin.

Weight Analysis & Control

NOTES ON THE PROBLEM OF THE OPTIMUM DESIGN OF STRUCTURES. W. S. Hemp. Coll. of Aeronautics, Cranfield, Note No. 73, Jan., 1958. 8 pp. Derivation of differential equations and a variational principle for the case of plates loaded in their own planes. These form the basis for approximate solutions in the form of optimum distributions of plate thickness and the corresponding stress distributions which are required to equilibrate given systems of external loads.

INITIAL AIRCRAFT WEIGHT PREDICTION. D. Howe. Coll. of Aeronautics, Cranfield, Note No. 77, Dec., 1957. 25 pp. 19 refs. Review of recent contributions to the problem of weight esti-

mation in order to comment upon their applicability, and, particularly, to suggest simple methods for use during the operations system investigation and initial project design stages. The work is not limited to structures but also includes equipment and systems.

Wings

SOME METHODS FOR THE STRUCTURAL DESIGN OF WINGS FOR APPLICATION EITHER AT AMBIENT OR ELEVATED TEMPERATURES. J. W. Semonian and R. F. Crawford. (ASME Semi-Annual Meeting, San Francisco, June 9-13, 1957.) ASME Trans., Feb., 1958, pp. 419-426. 11 refs. USAF-supported study of the bending load of three box-beam types: multiweb beams, characterized by two covers which are connected by two spanwise internal members at discrete spaces; wide-column rib-supported configurations; and beams represented by two covers which are connected by a continuous internal medium. The effect of aerodynamic heating is considered, but the thermal stresses resulting from differential expansion of the box-beam components are neglected. A chart is presented showing the optimum efficiency curves for all three configurations treated.

THE DESIGN OF A MULTI-CELL BOX IN PURE BENDING FOR MINIMUM WEIGHT. D. S. Houghton and A. S. L. Chan. Coll. of Aeronautics, Cranfield, Note No. 74, Nov., 1957. 28 pp. Derivation of two methods to determine optimum skin thickness, web thickness, and web pitch for use in a multi-cell box of given depth under a given bending load. Design graphs are presented in which the optimum geometry is plotted against the structural index for a given material.

THERMODYNAMICS

Combustion

INFLUENCE OF PRESSURE ON THE COMBUSTION OF LIQUID SPHERES. G. A. Agoston, B. J. Wood, and Henry Wise. (ARS Semi-Annual Meeting, San Francisco, June 10-13, 1957.) Jet Propulsion, Mar., 1958, pp. 181-188. 13 refs. Experimental investigation made on the combustion of a series of liquid organic hydroxy compounds and several heavy hydrocarbons at atmospheric and subatmospheric pressures. These data, in addition to flame distance measurements, were successfully correlated revealing quantitatively the influence of free convection. At subatmospheric pressures the change in burning rate is so modest that for practical purposes the burning rate of hexadecane drops less than 1,000 μ in diameter may be considered independent of pressure under free convection conditions.

FLAME REACTION RATES. A. L. Berlad. Convair Sci. Res. Lab. RN 10, July, 1957. 30 pp. 26 refs. Presentation of relations among the various chemical reaction velocities implicit in the behavior of several combustion parameters. Relations among these combustion parameters and their associated reaction velocities are examined and the utility of such combustion parameter measurements in calculating heat release rates of extremely reactive systems is discussed.

ON THE THERMODYNAMIC PROPERTIES OF PRODUCTS OF COMBUSTION OF HYDROCARBONS WITH AIR. Wu Chung-Hua. (Chinese J. Mech. Eng., No. 2, 1955, pp. 141-159.) Scientia Sinica, Oct., 1957, pp. 919-939. 16 refs. Analysis of the products of complete burning for any amount of hydrocarbon fuel with air up to a stoichiometric value. Results are presented in tabular form. Equations are also presented to determine the percentage of theoretical amount of fuel required for a given temperature of combustion products. Applications are made to steady flow combustion, afterburning in a turbojet engine, and isentropic expansion of combustion gases.

STABILITY OF PROPANE-AIR FLAMES IN VORTEX FLOW. A. E. Potter, Jr., E. L. Wong, and A. L. Berlad. US, NACA TN 4210, Feb., 1958. 27 pp. Measurement of the stability limits of propane-air vortex flames by means of a vortex burner in which the vortex strength is varied at constant flow rate. The blowoff velocity is proportional to the 0.73 power of the vortex strength and increases slightly with fuel concentration. The flames are stabilized by a stagnation or near-stagnation region induced by a pressure defect existing at the vortex center. When the vortex strength is made large, the pressure defect at the vortex center draws ambient air into the flame, causing a partial quenching of flames. H_2O_2, HCHO, higher aldehydes, CH_3OH, H_2, and CO are found in the combustion products of lean flames in strong vortices.

Heat Transfer

HEAT TRANSFER IN LAMINAR PIPE FLOW WITH UNIFORM COOLANT INJECTION. S. W. Yuan and A. B. Finkelstein. Jet Propulsion, Mar., 1958, pp. 178-181. ONR-sponsored analysis of the temperature distributions in a pipe for various fluid injection rates by solution of the energy equation in which the velocity distribution terms are obtained from a previous analysis. The heat transfer results, expressed as a local Nusselt Number, are presented in terms of the Péclet Number, the dimensions of the pipe, and the coolant flow rate. The relation between wall temperature and the rate of coolant injection is also calculated. The results also show that the heat transfer coefficient at the wall decreases with an increase in the rate of coolant injection, whereas it was previously found that the friction coefficient at the wall increases with an increase of fluid injection. Thus, the usual analogy between heat transfer and momentum transfer does not hold in porous wall cooling of pipe flow.

HEAT TRANSFER FROM HORIZONTAL CYLINDERS TO A TURBULENT AIR FLOW. B. G. van der Hegge Zijnen. Appl. Sci. Res., Sect. A, No. 2-3, 1958, pp. 205-223. 18 refs. Presenta-

tion of heat transfer measurements from wire and cylinders vibrating in air with both smooth and turbulent air flow of known intensity and scale of turbulence. The results show how the ratio between the Nusselt Number in turbulent flow and the Nusselt Number in smooth flow varies as a function of the Reynold Number, the intensity of turbulence, and the ratio between the scale of turbulence and cylinder diameter.

K TEORII TERMOGRAVITATSIONNOI KONVEKTSII V USLOVIIAKH TURBULENTNOGO REZHIMA. L. E. Ber. AN SSSR Otd. Tekh. Nauk Izv., Nov., 1957, pp. 75-83. In Russian. Derivation of approximate equations for the superposition of a forced and a free turbulent heat convection. The turbulent viscosity and heat conductivity are studied for the case of flow in a cylindrical duct using modified experimental data. A solution is also derived for the case of a circular vertical tube and the results are compared to those obtained experimentally.

VTOL & STOL

EFFECTIVENESS OF BOUNDARY-LAYER CONTROL, OBTAINED BY BLOWING OVER A PLAIN REAR FLAP IN COMBINATION WITH A FORWARD SLOTTED FLAP, IN DEFLECTING A SLIPSTREAM DOWNWARD FOR VERTICAL TAKE-OFF. K. P. Spreemann. US, NACA TN 4200, Feb., 1958. 32 pp. Experimental investigation on a wing with a 67% chord slotted flap in combination with a 33% chord plain rear flap equipped with a full-span blowing nozzle, conducted in a static-thrust facility at the Langley Aeronautical Laboratory. Results show that the plain rear flap alone with a low momentum coefficient for boundary-layer control provides larger turning angles than the combined slotted and plain flaps without boundary-layer control.

INFLUENCE DES EFFETS GYROSCOPIQUES D'UN TURBOREACTEUR SUR UN AVION DECOLLANT A LA VERTICALE. G. Ernst and J. Jardinier. Docaéro, Jan., 1958, pp. 19-28. 11 refs. In French. Investigation of the influence of gyroscopic effects of a turbojet on a VTO aircraft. Includes: derivation of the equations of motion - system of coordinates, general equations, and aerodynamic moments; study of the angular motion - solution of the system, study of particular cases (take off, low flight speed, high flight speed); compensation of gyroscopic effects - compensation principle (perfect and imperfect compensation); the influence of the compensation lag time - permanent harmonic motion; study of the disturbing motion - undercompensation, overcompensation, and perfect compensation of gyroscopic effects with lag time; and comparison of the three compensation cases.

WATER-BORNE AIRCRAFT

ON THE MAIN SPRAY GENERATED BY PLANING SURFACES. Daniel Savitsky and J. P. Breslin. IAS, SMF Fund Paper No. FF-18, Jan., 1958. 46 pp. 13 refs. Members, $0.75; nonmembers, $1.25. Theoretical and experimental investigation to determine the origin and the dependence upon the basic planing parameters of the main spray associated with prismatic planing hulls. It is found that the main spray originates locally at the stagnation line intersection with the chine and that the water contained in a spray comes from a strip of undisturbed surface fluid lying ahead of and parallel to the chine. The maximum spray height is found to be proportional to the square of the planing velocity, it increases almost linearly with increasing trim angle, does not vary strongly with deadrise angle, achieves a maximum height at a deadrise angle of 10°, and is independent of aspect ratio in the chines-wetted planing condition. Small vertical strips are very effective in reducing spray heights, while horizontal chine flares are ineffective.

COMPARISON OF HYDRODYNAMIC-IMPACT ACCELERATION AND RESPONSE FOR SYSTEMS WITH SINGLE AND WITH MULTIPLE ELASTIC MODES. R. W. Miller. US, NACA TN 4194, Feb., 1958. 30 pp. Experimental investigation using an elastic model consisting of a rigid prismatic float and a flexible wing, and comparison of the results with similar test results for a single-mode system and with theoretical solutions. Tests are conducted in smooth water at fixed trims of 3° and 9° with flight-path angles of 14° and 6°, respectively, and over a range of velocities. It is shown that applied accelerations are in agreement with those obtained by the method of NACA Report 1074, and that the higher modes present in the multimode system have no significant effect on the applied accelerations.

WIND TUNNELS & RESEARCH FACILITIES

INTERFERENCE EFFECTS BETWEEN TOTAL-PRESSURE PROBES IN THE BOUNDARY LAYER OF A SUPERSONIC WIND TUNNEL. J. R. Lacy. Texas U. DRL Rep. 420 (AFOSR TN 58-6) [AD 148045], Jan., 1958. 38 pp. Test results indicating the definite presence of mutual interference between total-pressure probes at a spacing between probes of approximately 0.025 to 0.030 inch. An approximate method of determining shock wave shape and location ahead of plane and axially symmetric bodies is utilized to provide an indication of minimum probe spacing to prevent mutual interference between probes of other sizes.

WIND-TUNNEL WALL INTERFERENCE EFFECTS ON OSCILLATING AEROFOILS IN SUBSONIC FLOW. W. P. Jones. Gt. Brit., ARC R&M 2943, 1957. 21 pp. 11 refs. BIS, New York, $1.35. Development of a theory for estimating the wall interference effects applicable only for a range of frequencies well below the frequency at which transverse vibrations of the air stream may be induced. The possibility of resonance occurring for certain combinations of tunnel height, fre-

quency of oscillation of airfoil, wind speed, and Mach Number pointed out by Runyan and Watkins, are confirmed. The method is applied to calculate aerodynamic derivatives for an oscillating flat plate in a wind tunnel of height equal to 4.75 airfoil chord and a Mach Number of 0.7. Results are tabulated for comparison with the known theoretical free-stream values, and it is shown that the influence of the walls is considerable even at frequencies of oscillation well below that of resonance. Pitching-moment damping for a range of Mach Numbers and low-frequency parameter values is estimated, and these values are in fairly good agreement with the measured values up to M = 0.8.

THE DESIGN, INSTRUMENTATION AND OPERATION OF THE UTIA LOW DENSITY WIND TUNNEL. Appendix I - THE DESIGN OF A MACH 2 AXIALLY SYMMETRIC NOZZLE FOR AN OPERATING PRESSURE OF 20 MICRONS Hg. Appendix II - THE USE OF THERMOCOUPLE WIRES FOR MEASURING AIR STAGNATION TEMPERATURE IN A LOW SPEED RAREFIED GAS FLOW. Appendix III - NEW STUDIES OF OUTGASSING EFFECTS OF PRESSURE PROBES IN FREE MOLECULE FLOW. K. R. Enkenhus. UTIA Rep. 44, June, 1957. 164 pp. 204 refs. Discussion of a continuous open circuit tunnel with vacuum pump drive designed to operate at Mach Numbers up to 5 over a range of pressures suitable for the study of rarefied gas flows. Booster-type oil diffusion pumps are used to provide a range of operating pressures from 0.001 to 0.070 mm. Hg. The calibration is given of axisymmetric nozzles for Mach 4, Mach 2, and subsonic flow. These nozzles have solid walls and are operated at pressures of 0.040, 0.020, and 0.008 mm. Hg, respectively. The flow in the supersonic nozzles is essentially a continuum flow at low Reynolds Number with the boundary layer filling most of the jet, while in the subsonic nozzle the density is low enough to produce slip on the walls.

ON SOME ASPECTS OF THE USE OF SHOCK TUBES IN AERODYNAMIC RESEARCH. B. D. Henshall. Gt. Brit., ARC R&M 3044, 1957. 103 pp. 43 refs. BIS, New York, $5.40. Survey of existing shock tube theory and experimental results, and formulation of the basic ideal shock tube theory, using performance charts affording a rapid method for the aerodynamic design of shock tubes with air as working fluid. It is shown that experimental results diverge from the theory because of the presence of viscous effects. Another theory of shock tube flow is developed, using a new analytical approach, which includes the effects of boundary layer growth on the tube walls and explains several features of the actual flow patterns which are at variance with ideal nonviscous theory. This developed theory is restricted to weak shock waves and laminar and incompressible boundary layers. A shock tube installation is developed and one application is illustrated, i.e., the study of unsteady flows.

A THEORETICAL ANALYSIS OF A NEW TYPE OF HEATER FOR AN INTERMITTENT HYPERSONIC WIND TUNNEL. Antonio Ferri, P. A. Libby, and Victor Zakkay. USAF WADC TN 57-264 [AD 130911], July, 1957. 40 pp. Discussion of the need for high stagnation temperature and pressures for wind tunnels with test Mach Numbers of more than five and of the limitations of conventional heaters. A new type of heater is proposed, involving the compression of air first heated by a conventional convection heater. This compression, being as close to adiabatic as possible, is performed by a floating piston actuated by cold, high pressure air. The compression heater is analyzed under ideal conditions to establish the characteristics required for its uses with an intermittent hypersonic wind tunnel. Heat transfer from the compressed high temperature air to the walls of the heater during tunnel operation is discussed. It is indicated how the use of a porous liner with cold air injection can sufficiently reduce this heat transfer so that the idealized heater characteristics can be practically realized.

REAL GAS EFFECTS ON SHOCK-TUBE PERFORMANCE AT HIGH SHOCK STRENGTHS. J. L. Stollery. Gt. Brit., RAE TN Aero. 2413, Nov., 1957. 24 pp. 13 refs. Calculations to determine the flow conditions behind shock waves in argon-free air of shock Mach Numbers up to 35. Hydrogen has been assumed as the driving gas. Test results indicate that real gas effects on pressure and velocity behind the shock are small, but have a noticeable effect on density, temperature, Mach Number, and, particularly, stagnation pressure. There is a marked increase in shock strength if the driver gas is heated. It is found that complete simulation of flight conditions in a shock tunnel is very difficult, basically because of the dissimilar compression and expansion cycles used to generate the flow, and a pressurized channel will usually be needed. Complete simulation of the flow near the stagnation point is however much simpler.

WALL EFFECTS IN SHOCK TUBE FLOW. R. J. Emrich and D. B. Wheeler, Jr. Phys. Fluids, Jan.-Feb., 1958, pp. 14-23. 24 refs. ONR-supported measurements of the shock strength, average density across the tube, and pressure at the walls; and a comparison with explicit predictions by Trimpic-Cohen and Mirels-Braun. Under conditions where the theories should apply, they predict shock attenuation and values of the flow variables sufficiently well to justify as essentially correct the assumptions that the turbulent boundary layer produced by the shock is similar to the boundary layer observed in steady flows, and that waves generated by wall effects can be considered as one-dimensional. A need for some modifications of the theories is indicated, however, by lack of quantitative agreement in certain cases. Considerable mixing of the hot and cold gases is observed. Neither theory attempts to explain the mixing, nor takes into account its effects on wave propagation.

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Education & Training

Retention of Rated AFROTC Officers. Eli S. Flyer and Abraham Carp. *USAF PTRC DR TN 57-126 [AD 134258]*, Oct., 1957. 33 pp. Study to identify factors associated with career attitudes among AFROTC pilot training graduates, and to devise methods to increase their retainability. Results indicate that career interest is highly related to attitudes toward flying, military life, and job opportunities in civilian life.

I—The Red Education Challenge. Albert Parry. **II—Minuteman to Missileman.** George T. Cahill, Jr. **III—US-USSR Educational Systems; A Comparison.** William P. Lear. **IV—Training Potentialities of Synthetic Missiles.** J. Gordon Vaeth and John Huson. *Missiles & Rockets*, Dec., 1957, pp. 75–80, 119, 120.

I—The American System of Education and Training of Mechanical Engineers. H. S. Arms. **II—Education of Engineers in European Countries.** S. J. Davies. *ME Proc.*, No. 6, 1957, pp. 215–230; Discussion, pp. 231–244.

Electronics

Dinamicheskie Kharakteristiki Serdechnik›v s Priamougol'noi Staticheskoi Petlei Gisterezisa (Vliianie Vikhrevykh Tokov). M. A. Rozenblat. *Avtom. i Telemekh.*, Jan., 1958, pp. 75–84. In Russian. Study of the effect of eddy currents on the dynamic hysteresis loop, on the differential magnetic permeability, and on the dynamic coercive force of cores with rectangular static hysteresis loops.

Printed Wiring Design. B. J. Strasler. *Mil. Electronics*, Feb., 1958, pp. 16–20. Description of printed wiring techniques used for the design of electronic equipment or circuits; includes the advantages and disadvantages of such procedures.

Foamed Plastics for Structural Functions in Electronic Equipment. Russell Thielman. *Elec. Mfg.*, Jan., 1958, pp. 67–73. Application of foamed plastics to shield the equipment from severe environmental conditions.

Research and Development on Magnetic Films. John T. Doherty. *USAF WADC TR 56-537 [AD 142077]*, Oct., 1957. 55 pp.

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Über stabilisierte Netzgeräte mit Transistoren. Ernst Baldinger and Wolfgang Czaja. *ZAMP*, Jan. 25, 1958, pp. 1–25. 23 refs. In German. Discussion of stabilized voltage supplies employing transistors.

Some Applications of the Isometric Circle Method to Impedance Transformations Through Lossless Two-Port Networks. E. Folke Bolinder. *Acta Polytechnica*, No. 6 (232), 1957. 22 pp. 17 refs.

Some Features of the Piezoelectric Effect of Barium Titanate as Measured Statistically. E. K. Dobrer and K. N. Karmen. *Sov. Phys.-Tech. Phys.*, Mar., 1957, pp. 455–458. Translation. Investigation showing that upon application of a mechanical stress in a plane perpendicular to the direction of the preliminary polarization, a linear variation arises only up to a certain value of the mechanical stress. With an increase of the mechanical stress this linearity no longer holds, a saturation of the piezoelectric polarization sets in.

Amplifiers

New Types of D.C. Amplifier. II—The Reflex-Monitor System. D. J. R. Martin. *Electronic & Radio Engr.*, Feb., 1958, pp. 56–62. Application of the cascade-balance principle to a direct-coupled amplifier of the type using overall drift-correction. It corrects alternately its own drift and the drift of the main amplifier.

Nekotorye Optimal'nye Sootnosheniia v Ideal'nom Magnitnom Usilitele pri Upravlenii Signalom Peremennogo Toka. K. S. Volchkov. *Avtom. i Telemekh.*, Jan., 1958, pp. 85–94. In Russian. Analysis of the performance of an ideal saturating magnetic amplifier with an active load. Includes determination of the relation between the coefficient of frequency distortion of the amplifier and its time constant.

Magnetic Amplifiers with Half-Cycle Response. I, II. B. W. Glover. *Elec. Energy*, Jan.; Feb., 1958, pp. 2–9; 58–64. 18 refs. Consideration of the basic circuits having inherent half-cycle response, neglecting the effect of external feedback arrangements. Includes diagrams as well as a classification of four-core duo-directional full-wave circuits according to their circuit arrangement.

Antennas

Measuring Antenna Performance. *Aerovox Res. Worker*, Dec., 1957. 5 pp. Brief review of some measurement techniques.

Antenna Pattern Range Speeds Countermeasures Work. Ben H. Ciscel and John Hill. *Av. Age*, Feb., 1958, pp. 102–105. Description of a radar range to help predict radiation patterns for ECM development.

Bearing Memory Improves Direction Finder. Roy E. Anderson. *Electronics*, Jan. 31, 1958, pp. 44–48. Development of a Doppler direction-finder system in which the action of a rotating antenna is simulated by a 150-ft.-diameter circular array of 31 antennas.

Effect of Antenna Height on Ultra-Short Wave Field Intensity in a Diffractive Region. I—Case of Low Antennae. P. Szulkin. *Acad. Pol. Sci. Bul.*, No. 5, 1957, pp. 301–306.

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Circuits & Components

Cathode-Coupled Flip-Flop; A Reliable Design Procedure. T. G. Clark. *Wireless World*, Jan., 1958, pp. 24–27. Analysis of circuit operation, including the principles underlying the design and calculation of pulse duration.

Band-Pass Filter Design Technique. D. R. J. White. *Electronics*, Jan. 3, 1958, pp. 79–81. Presentation of universal curves to provide design information for Butterworth and Tchebycheff stagger-tuned networks for band-pass amplifiers.

High Frequency Parameters of Transistors and Valves. J. Zawels. *Elec. Eng.*, Jan., 1958, pp. 15–17. Development of high-frequency equivalent circuits in the common-cathode, common-grid, and common-anode configurations. Approximations which may be made as a result of differing impedance levels are indicated.

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Electronic Switch Doubles as Cathode Follower. R. Benjamin. *Electronics*, Jan. 17, 1958, pp. 81–83.

Communications

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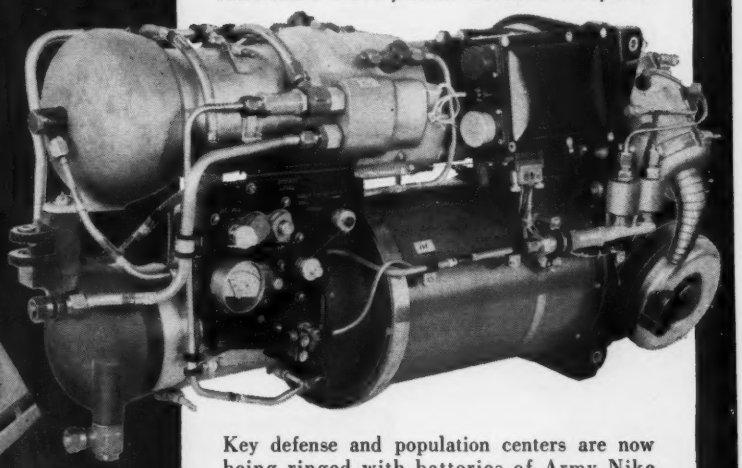

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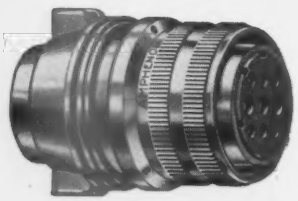

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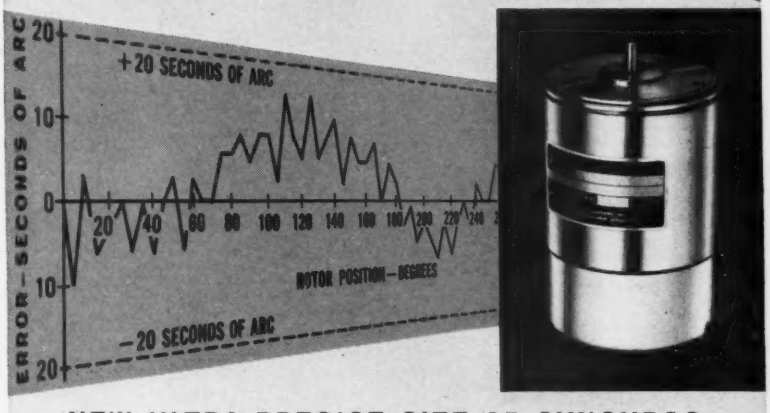

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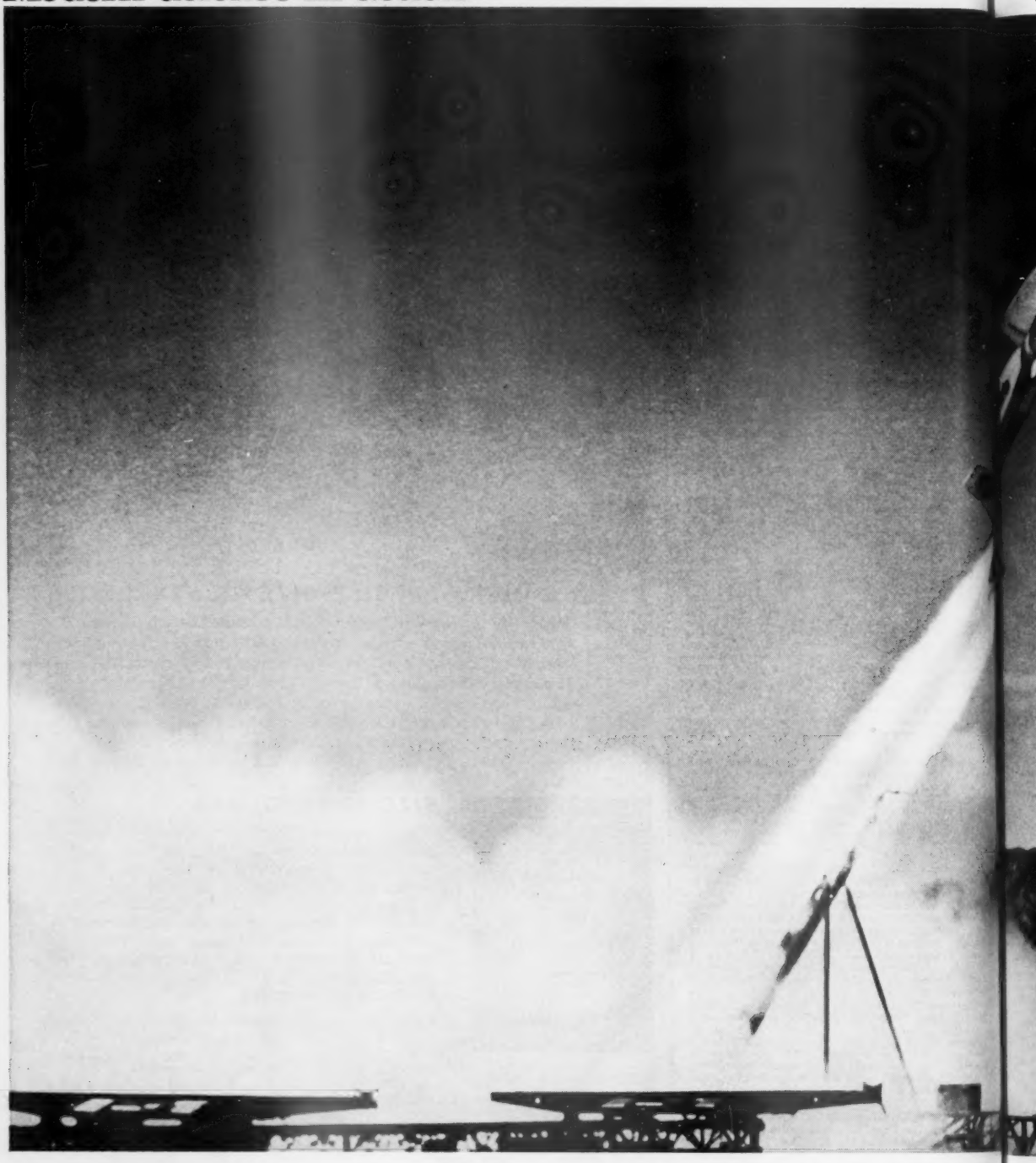

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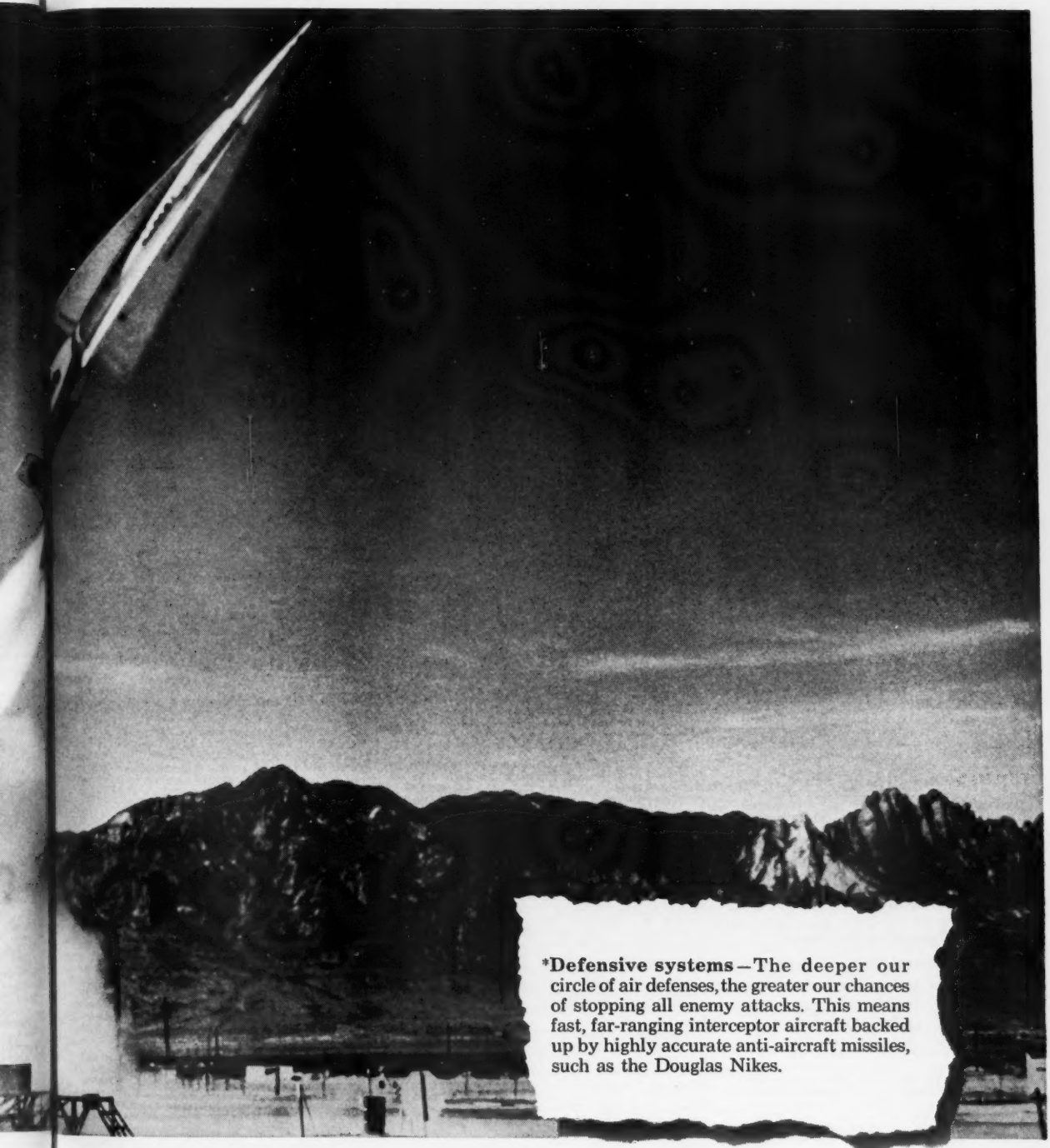

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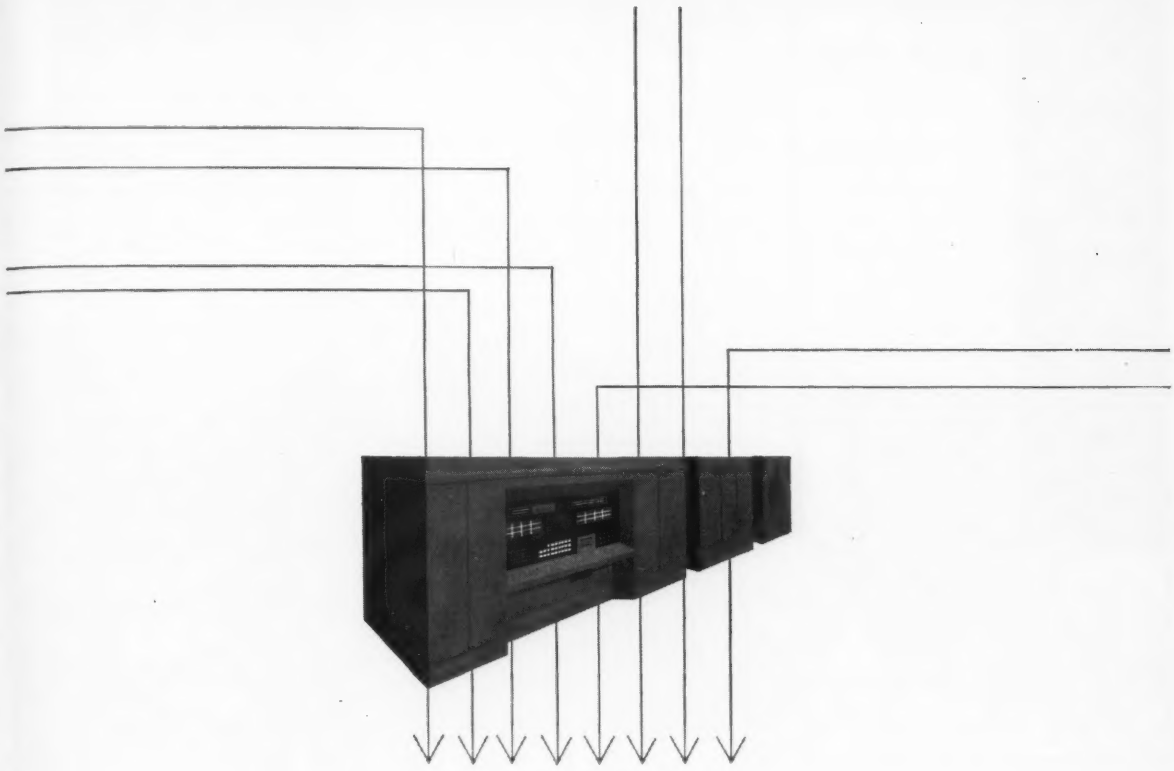

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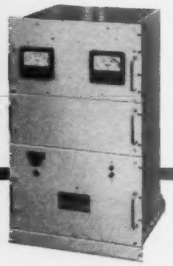

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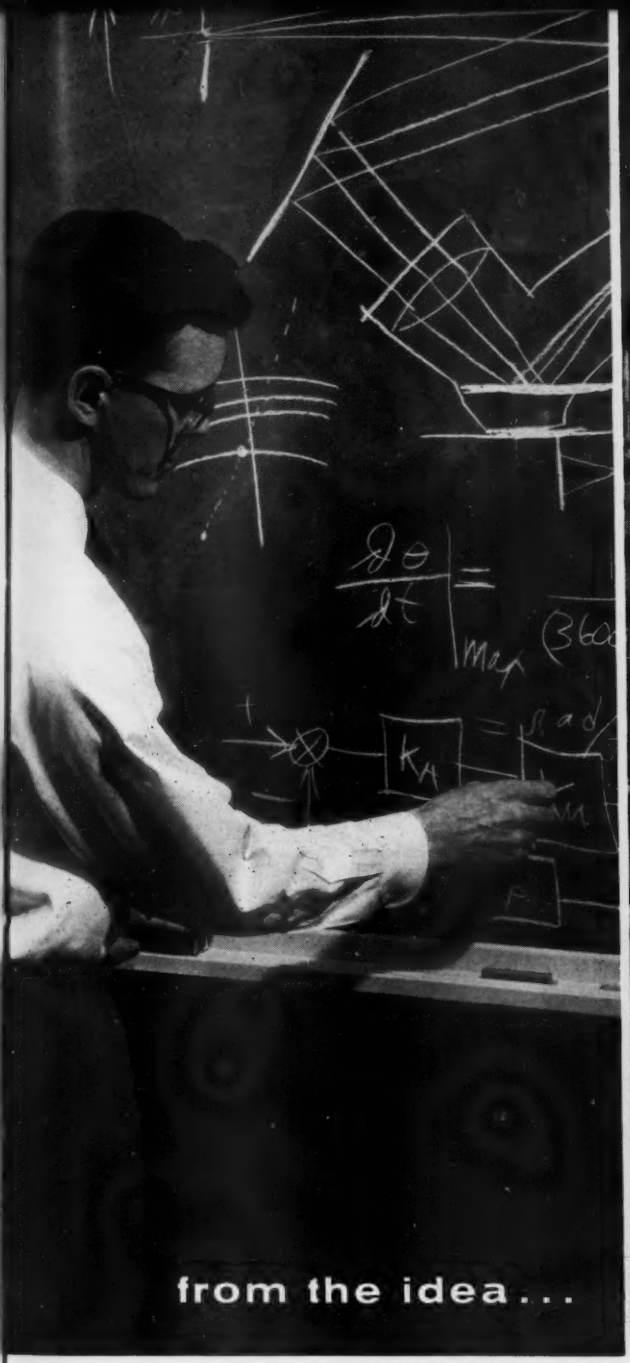

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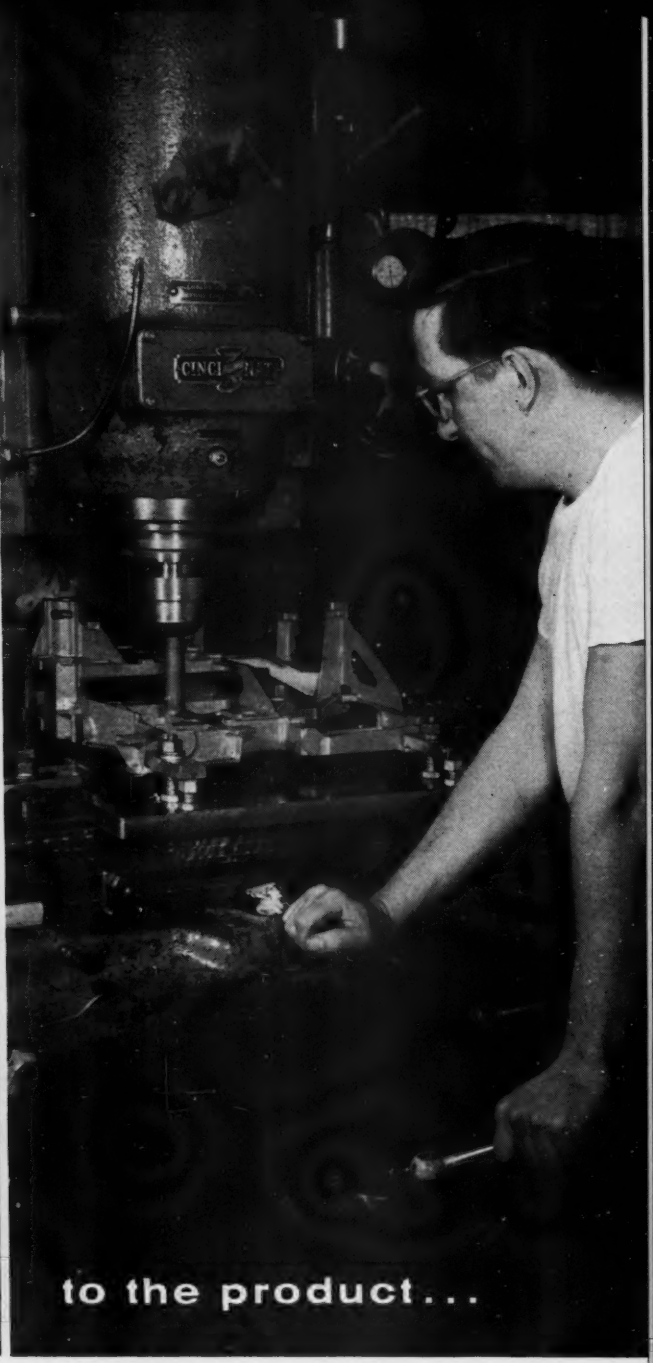

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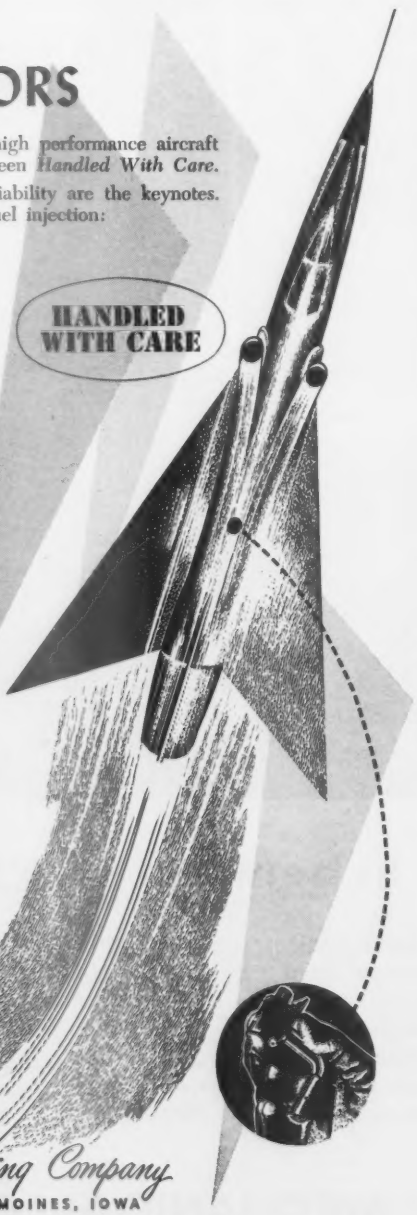

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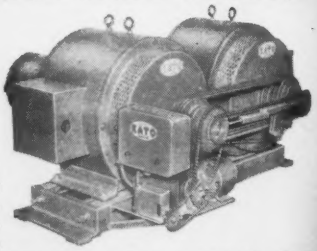

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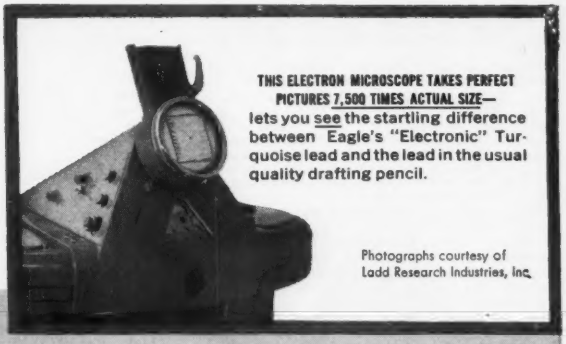

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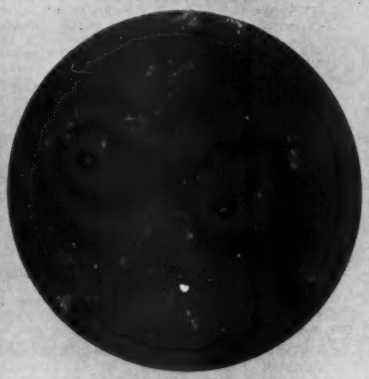

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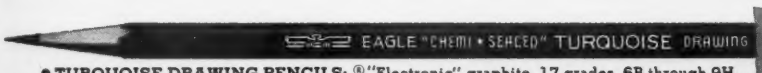

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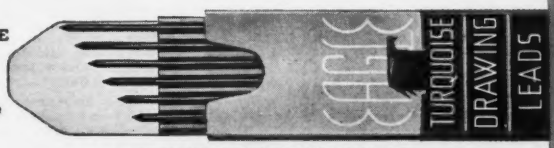

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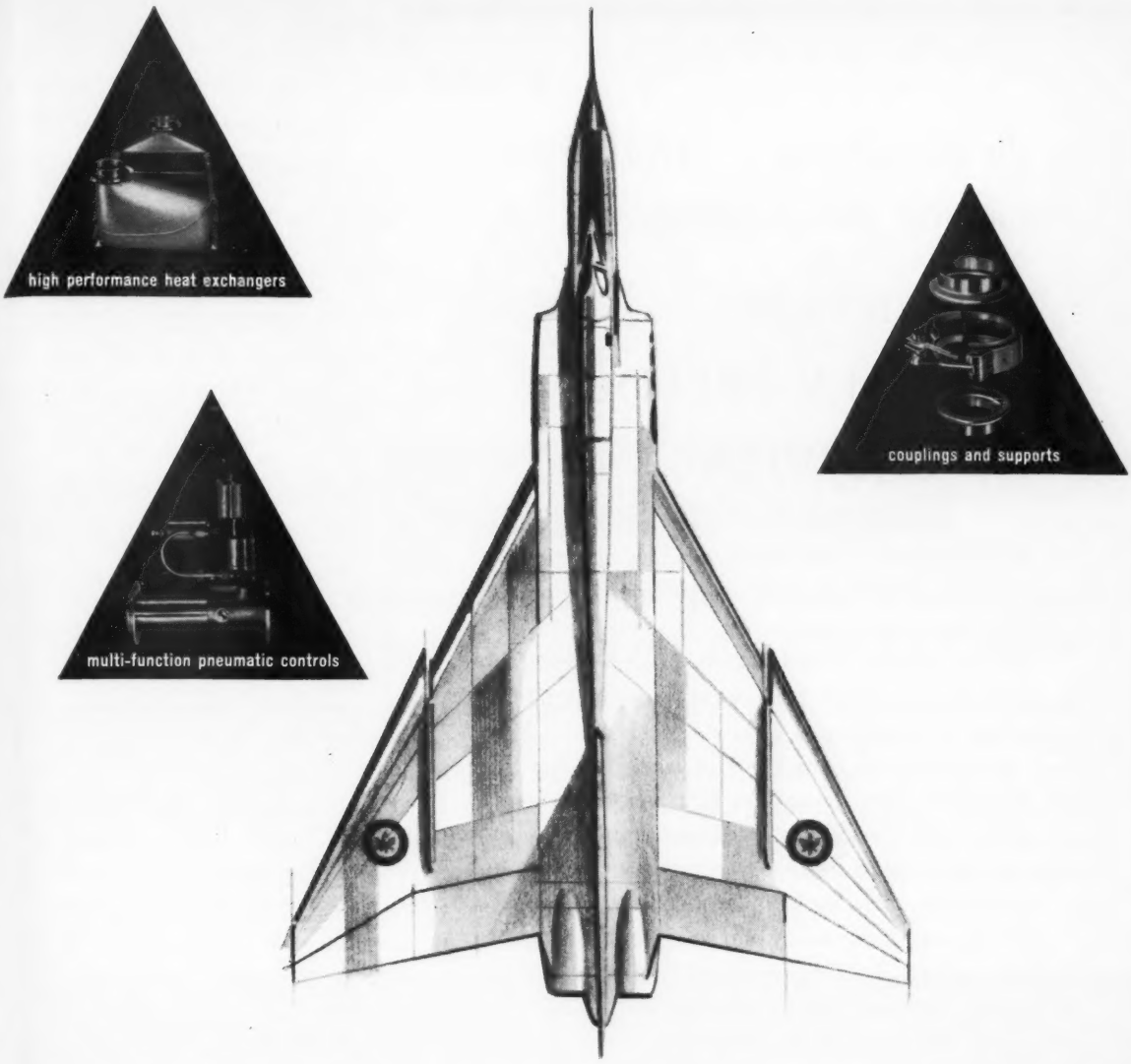

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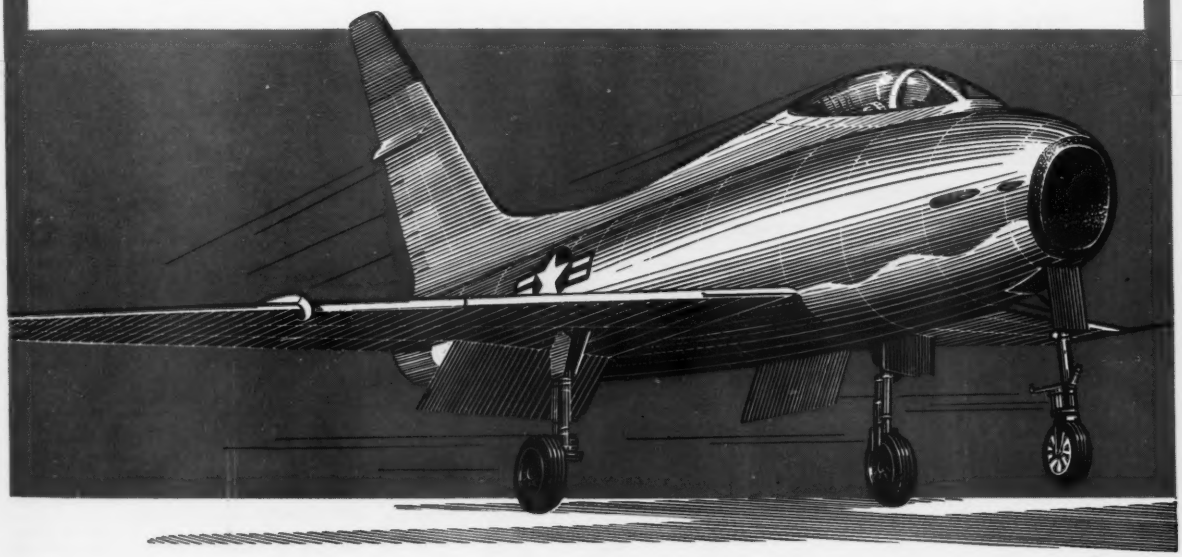

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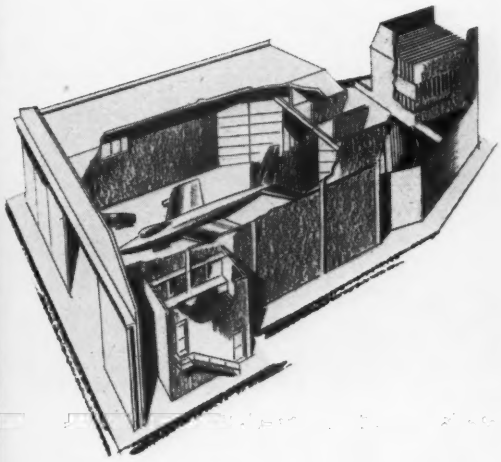

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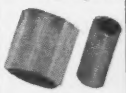

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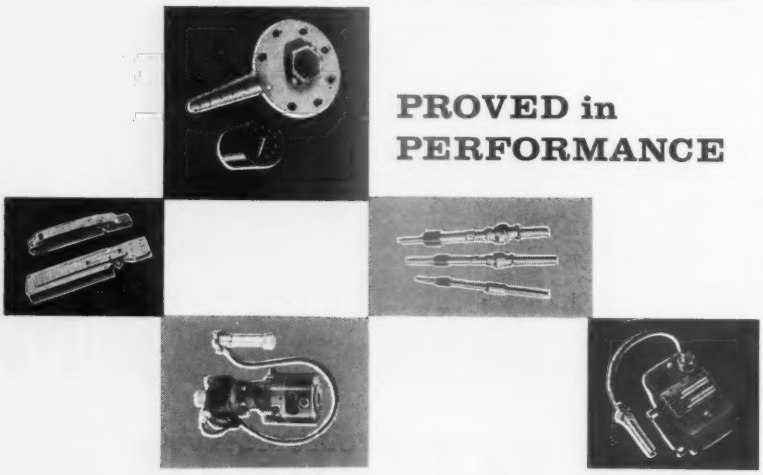

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On the Velocity of Formation of Lüders Bands. T. Y. Thomas. *J. Math. & Mech.*, Mar., 1958, pp. 141–148. ONR-supported solution using the Prandtl-Reuss equations for plastic flow and certain compatibility conditions in order to obtain the velocity of formation.

The Lüders Band Problem. T. Y. Thomas. *J. Math. & Mech.*, Jan., 1958, pp. 17–27. 12 refs. ONR-supported investigation of a flat plate subjected to a slowly increasing load, up to the point where the tension reaches the yield stress of the material.

Plates

Elastic-Plastic Bending of Non-Homogeneous Orthotropic Circular Plates. II. W. Olszak and J. Murzewski. *Arch. Mech. Stosowanej*, No. 5, 1957, pp. 605–630. Determination of the bending modes using the differential equations of the continuity of deformation and equilibrium, as well as algebraic equations of the principal curvatures a_1 and a_2 depending on the buckling moments m_1 and m_2.

Thermal Stress

The State of Stress and Displacement in a Thin Anisotropic Plate due to a Concentrated Source of Heat. Jerzy Mossakowski. *Arch. Mech. Stosowanej*, No. 5, 1957, pp. 565–577. Development of a relatively general method for solving problems of thermal stress in thin anisotropic plates. The method is illustrated by some simple examples, and the influence of thermal and elastic anisotropy on stress distribution is shown.

Inelastic Design Steps Up Performance. G. H. Sprague and P. C. Huang. *SAE J.*, Jan., 1958, pp. 46–49. Discussion of a method for weight saving using inelastic designs for thermal stresses. Taking advantage of temperature gradient shapes can improve the efficiency of the structure within the limits of buckling strength and allowable deformation.

Transient Temperature Distribution in Aircraft Structures. Irving Frank. *J. Aero. Sci.*, Apr., 1958, pp. 265–267. USAF-sponsored presentation of an analytical method for temperature distribution in an ordinary aircraft section.

Some Remarks Upon the Problem of Temperature Shock in Aircraft. F. Bollenrath. (*NATO AGARD 4th Structures & Materials Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 90*, Aug., 1956. 12 pp. Discussion of structural problems associated with heating and large temperature gradients. The thermal stresses due to a nonstationary distribution of temperature are calculated for a gas moving at high speed.

Effets Thermiques Dans le Calcul de la Résistance des Structures d'Avions et d'Engins. N. J. Hoff. *NATO AGARD Rep. 52*, Jan., 1956. 111 pp. 69 refs. In French. Review of the laws controlling the aerodynamic heating of supersonic aircraft, and a discussion of heat transmission inside the wings by conduction and radiation. Thermal stresses and their effect on the buckling of rods and thin plates are examined, as well as the problem of creep and its effect on stress distribution.

Thermodynamics

O Temperaturnoi Zavisimosti Teploemkosti Tverdykh Tel. N. N. Sirota. *AN SSSR Dokl.*, Aug. 11, 1957, pp. 901–903. In Russian. Analysis of the possibility of computing the temperature dependence of the specific heat of solids, taking into account the frequencies described by a law similar to that of Gauss.

Enthalpy Charts: For Dissociating Gas Mixtures in the Temperature Range 600 deg to 4,000 deg K. H. Reichert. *Gt. Brit., ARC R&M 3015* (Aug., 1950) 1957. 20 pp. BIS, New York, $0.99.

The Determination of the Equation of State from Wave-Front Observations. Appendix—Example of a Slightly Imperfect Gas. E. F. Lype. (*ASME Annual Meeting, New York, Nov. 25–30, 1956.*) *ASME Trans.*, Jan., 1958, pp. 1–8; Discussion, pp. 8–10. Derivation of differential equations for obtaining the thermodynamic properties and establishment of the relationship between rarefaction waves and equation of state.

Combustion

Ninth Quarterly Technical Status Report on Non-Stationary Surface Combustion Studies (Covering Period from 15 Sept. to 15 Dec., 1957.) D. Perper, N. Thomas, and Domenic Bitondo. *ADC Rep. 410/R-12/34*, 1958. 6 pp. USAF-sponsored investigation.

Gorenie v Kamere Peremennogo Secheniia. E. Larish. *Rev. Méc. Appl.*, No. 1, 1957, pp. 55–60. In Russian. Derivation of a solution to the problem of flame propagation in a combustible gas mixture moving in a plane or axisymmetrical chamber with arbitrary profile variation. Application of results to the determination of the area ratio for complete combustion.

O Kriticheskikh Usloviiakh Podzhiganiia Goriuchikh Gazovykh Smesei Nagretymi Tverdymi Telami. A. I. Rozlovskii. *AN SSSR Dokl.*, Dec. 1, 1957, pp. 651–654. 17 refs. In Russian. Discussion of the critical conditions for the ignition of gas-mixture fuels by heated solid bodies.

Physical Characteristics and Test Conditions of an Ethylene-Heated High-Temperature Jet. Roland D. English, Abraham Spinak, and Eldred H. Helton. *U.S., NACA TN 4182*, Jan., 1958. 28 pp.

Effect of Radical Recombination Kinetics on Specific Impulse of High Temperature Systems. Kenneth A. Wilde. *Jet Propulsion*, Feb., 1958, pp. 119, 120. Determination of the kinetic impulse between the two conventional limiting conditions of frozen and equilibrium flow, obtained as a function of recombination rate constant, chamber pressure, and motor diameter.

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XUM

Some Observations of Flame Stabilization in Sudden Expansions. Peter A. Ross. *Jet Propulsion*, Feb., 1958, pp. 123–125. Investigation to determine the oscillating effects on the limits of stabilization when the length-to-diameter ratio of the chamber is large.

Flame Quenching. B. S. Massey and B. C. Lindley. *RAeS J.*, Jan., 1958, pp. 32–42. 102 refs. Study of various aspects of combustion, including the means of ignition, ignition temperatures, velocity of propagation, and inflammability limits of various hydrocarbons in air and oxygen, in order to establish a basis for the discussion of flame quenching mechanisms.

Analysis of Heat-Driven Oscillations of Gas Flows. III—Characteristic Equation for Flame-Driven Oscillations of the Organ-Pipe Type. IV—Discussion of the Theoretical Results Concerning Flame-Driven Oscillations. H. J. Merk. *Appl. Sci. Res., Sect. A*, No. 2–3, 1958, pp. 175–204. 19 refs.

On Radiation from Combustion Gas. Syōgo Matsunaga. *Jet Propulsion*, Feb., 1958, pp. 125, 126. Presentation of a method of burning gas to obtain more radiation than produced by the usual combustion procedure.

Heat Transfer

On the Relation of Surface Friction and Heat Transfer. E. A. Sidorov. *Sov. Phys.-Tech. Phys.*, Mar., 1957, pp. 499–504. 22 refs. Translation.

Rasprostranenie Teplovoi Volny, Blizkoi k Sfericheskoi. E. I. Andriankin and O. S. Ryzhov. *AN SSSR Dokl.*, Aug. 11, 1957, pp. 882–885. In Russian. Study of the propagation of a thermal wave of a nearly spherical shape.

An Asymptotic Method for Free Convection Past a Vertical Plate. Joe E. Foote. *ZAMP*, Jan. 25, 1958, pp. 64–67. Reduction of the problem of a free flow on an irregularly heated wall to the calculation of a series of functions satisfying a linear differential equation with constant coefficients.

Remarks on the Paper by M. Finston: "Free Convection Past a Vertical Plate." Frank Niuman and Karl Pohlhausen. *ZAMP*, Jan. 25, 1958, pp. 67–69. Reduction of the exact solution, derived by M. Finston for the natural convection of a vertical plate whose surface temperature is changed according to a potential law, to a one-parameter system for a given Prandtl Number. Some curves are presented for air ($Pr = 0.733$).

Nonstationary Thermal Conductivity in Laminar Bodies. M. G. Kogan. *Sov. Phys.-Tech. Phys.*, Mar., 1957, pp. 467–475. 11 refs. Translation. Analysis of thermal conductivity in nonhomogeneous laminar bodies (one-dimensional, axially symmetric, and centrally symmetric problems) due to the action of sources located within the layers and on surfaces of separation, which includes the heat exchange with the surrounding medium.

Turbulent Heat Transfer in the Thermal Entrance Region of a Pipe with Uniform Heat Flux. E. M. Sparrow, T. M. Hallman, and R. Siegel. *Appl. Sci. Res., Sect. A*, No. 1, 1958, pp. 37–52. 11 refs. Analysis using a method similar to Graetz's formulation for the laminar thermal entry region. Local and fully developed Nusselt Numbers are presented for fluids with Prandtl Numbers ranging from 0.7 to 100 and with Reynolds Numbers between 5×10^4 and 50×10^4.

Simple Solutions of the Partial Differential Equation for Diffusion (or Heat Conduction). S. C. Jain. *Royal Soc. (London) Proc., Ser. A*, Jan. 14, 1958, pp. 359–374. 12 refs. Investigation showing that the solutions for finite solids of various shapes and under various conditions can be derived from simple solutions rigorously applicable to linear diffusion in a semi-infinite slab. Tables and graphs are presented showing the relation between the numerical values obtained from the present method and those obtained by much more laborious procedures.

VTOL & STOL

Convertiplanes. R. L. Lichten. *SAE J.*, Jan., 1958, pp. 30–32. Analysis of the capabilities of convertiplanes in the VTOL and forward flight spectra.

Full-Scale Wind-Tunnel Tests of the Longitudinal Stability and Control Characteristics of the XV-1 Convertiplane in the Autorotating Flight Range. Appendix A—**Analysis of a V-Tab Horizontal Tail.** Appendix B—**Estimation of Rotor Downwash.** Appendix C—**Estimation of Stick-Motion Stability.** David H. Hickey. *U.S., NACA RM A55K21a*, May 17, 1956. 64 pp.

Talking Point: Has the Transport Helicopter a Future? *Air BP*, No. 6, pp. 10–13. Discussion of various VTOL configurations and their potential commercial uses.

B.E.A. Looks Ahead. *The Aeroplane*, Jan. 24, 1958, pp. 115–117. Discussion of provisional requirements worked out for a VTOL passenger, mail, and freight aircraft. Includes performance, handling, air conditioning, and operational problems.

Jet-Deflection Devices. Uwe H. von Glahn and John H. Povolny. *SAE J.*, Jan., 1958, pp. 64, 65. Discussion of some possible lift-augmentation and direction-control configurations for jet-powered VTOL and STOL aircraft.

The Aerodyne Concept. Alexander M. Lippisch. *Interavia*, Jan., 1958, pp. 51–55. Establishment of general specifications and discussion of the solutions of different problems involved in the design of wingless aircraft.

Ryan Vertiplane. Charles Williams. *Am. Helicopter*, Dec., 1957, p. 10.

VTOL Flight Test and Development. C. E. Myers, Jr. *Interavia*, Jan., 1958, pp. 57–59. Review of the significant development projects between 1954 and the present, including some recommendations for the future.

STOL for Mercantile Aviation. D. M. Desoutter. *Aeronautics*, Jan., 1958, pp. 32–41. Design, performance, and system characteristics of the Scottish Aviation Twin Pioneer. Also includes discussion of various configurations for both civil and military roles.

Propulsive Wing May be Answer to STOL Problem. Robert J. Spindler. *Av. Age*, Feb., 1958, pp. 38–43. Discussion on the application of supercirculation to an aircraft wing—alternating the velocity field around a wing by trailing edge blowing.

American Development in STOL and VTOL Aircraft. C. W. Meshier. (*NATO AGARD 9th Flight Test Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 86*, Aug., 1956. 15 pp. Discussion of low-speed flight problems.

Wind Tunnels & Research Facilities

Electronic Systems at China Lake. Neil Givens. *Mil. Electronics*, Jan., 1958, pp. 10–13, 15. Discussion of general characteristics and performance of devices for exact synchronization and control purposes of modern weapons.

Research in the U.S. Naval Ordnance Laboratory Ballistics Ranges. Paul A. Thurston. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 137*, July, 1957. 28 pp. Description of the NOL ballistic range and a discussion of the complementary nature of wind tunnels and ballistics ranges.

Short Notes on Model-Making and Force-Measuring Techniques. E. Dobbinga and G. Prast. (*NATO AGARD 8th Wind-Tunnel & Model-Testing Panel, Rome, Feb. 20–25, 1956.*) *NATO AGARD Rep. 18*, Feb., 1956. 26 pp. Presentation of a series of papers which include three special methods in model making used at the N.L.L., a description of model making machines, and some force-measuring techniques.

Note on Hydrogen as a Real-Gas Driver for Shock Tubes. Paul W. Huber. *J. Aero. Sci.*, Apr., 1958, p. 269. Presentation of a computation for real-gas hydrogen driving real-gas air. The resulting plot of diaphragm pressure ratio versus shock Mach Number is presented for two cases of driver pressure.

Blocking in the Supersonic Wind Tunnel. Bain Dayman, Jr. *J. Aero. Sci.*, Apr., 1958, pp. 264, 265. Army-sponsored experimental investigation to obtain a reliable method of predicting the blocking characteristics of models during an attempted start.

The Use of Gun-Launched Models for Experimental Research at Hypersonic Speeds. Alvin Seiff. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 138*, July, 1957. 19 pp. Description of two methods for extending gun-launched model tests into the hypersonic Mach Number range, one of them using a counter-current supersonic air stream for attaining $M = 13$, the other replacing powder-gas by compression-heated helium.

Interference Corrections for Asymmetrically Loaded Wings in Closed Rectangular Wind Tunnels. H. C. Garner and W. E. A. Acum. *Gt. Brit., ARC R&M 2948* (Sept., 1953) 1957. 38 pp. 10 refs. BIS, New York, $1.98. Investigation of tunnel interference in relation to aerodynamic measurements on a six-component balance, and discussion of its basic theory. The tunnel-induced upwash is expressed in terms of the wing load and four quantities dependent on the tunnel shape.

NACA Hypersonic Rocket and High-Temperature Jet Facilities. Paul E. Purser and Aleck C. Bond. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 140*, July, 1957. 13 pp. Discussion of the possibility of extending rocket-model research to hypersonic speeds, and brief description of several high-temperature jet facilities for research on structures and materials.

The Blow-Down Wind Tunnel at Aachen. A. Naumann, A. Heyser, and W. Trommsdorff. (*NATO AGARD 9th Wind-Tunnel & Model-Testing Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 69*, Aug., 1956. 20 pp. Discussion of the construction, installation, and application of the first stage of the tunnel. Also included are the general layout of the complete tunnel and a simple analytical estimation of the aerodynamic performance of such a tunnel.

A Supersonic Wind Tunnel for Mach Numbers up to 3.5. L. E. Leavy. (*NATO AGARD 9th Wind-Tunnel & Model-Testing Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 70*, Aug., 1956. 31 pp. Description of the requirements, design, and construction of the Avro 27 in. × 30 in. intermittent blow-down tunnel.

The Hypersonic Facility of the Polytechnic Institute of Brooklyn and its Application to Problems of Hypersonic Flight. Antonio Ferri and Paul A. Libby. (*NATO AGARD Rep. 136*, July, 1957.) *USAF WADC TR 57-369 [AD 130809]*, Aug., 1957. 47 pp. 22 refs.

The Light Gas Hypersonic Gun Tunnel at A.R.D.E., Fort Halstead, Kent. R. N. Cox and D. F. T. Winter. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 139*, July, 1957. 24 pp. Description of the tunnel, including a discussion of its instrumentation and presentation of some flow-quantity measurements.

Tube Wind Tunnel—A Special Type of Blow-down Tunnel. H. Ludwieg. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 143*, July, 1957. 11 pp. Description of a tunnel, the air container of which consists of a long cylindrical tube. A constancy of stagnation pressure and temperature is reached without use of any control valve and heat accumulator by pre-accelerating the air with an expansion wave.

Preliminary Considerations for a Hypersonic Test Stand. Appendix A—**Derivation of the Test Stand and Vacuum System Pressure Ratios.** Appendix B—**Derivation of the Condensation Limit Curve for Variable Specific Heats Ratio.** Appendix C—**Derivation and Analysis of the Test Stand Running Time.** Appendix D—**Derivation of the Reynolds Number Equation.** Charles A. Scolatti and Anthony W. Fiore. *USAF WADC TN 57-343 [AD 142239]*, Oct., 1957. 64 pp. 41 refs. Description of a tunnel which will operate at stagnation temperatures ranging from 1,100°R. to 3,000°R. and at stagnation pressures ranging from 100 psia to approximately 2,500 psia over a Mach range from 8.0 to 15.0.

Hypersonic Shock Tube Equipment at the National Physical Laboratory, U. K. D. L. Schultz and B. D. Henshall. (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 147*, July, 1957. 23 pp. Description of the device giving a Mach Number of approximately nine. Performance charts illustrating full-scale flight conditions are presented, and a unified electronic timing and recording system is described.

Nozzle and Contraction Shapes of the R.A.E. 3ft. × 3ft. Supersonic Wing Tunnel. A. Stanbrook. *Gt. Brit., ARC CP 375*, 1957. 9 pp. BIS, New York, $0.36.

Minimum Length of a Shock-Tube, for Given Working Times. Lucian Dumitrescu. (*Stud. Cerc. Mec. Aplic.*, Apr.-June, 1956, pp. 337–353.) *Rev. Méc. Appl.*, No. 1, 1957, pp. 61–77.

Turbulence Measurements in Supersonic Flow with the Hot-Wire Anemometer. B. Wise and D. L. Schultz. *Gt. Brit., ARC CP 366* (Dec., 1955) 1957. 27 pp. 12 refs. BIS, New York, $0.72. Description of apparatus capable of separating the mass flow and stagnation temperature fluctuation in free-stream turbulence.

Air Supply for Blow-Down Wind Tunnels. E. J. Stollenwerk. (*NATO AGARD 9th Wind-Tunnel & Model-Testing Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 88*, Aug., 1956. 19 pp. Description of an air-supply system for E-1 tunnel at Arnold Engineering Development Center. Emphasis is placed on problems of air storage and pressure control, flow equalization downstream of the control valve, and temperature control.

Loads on a Model During Starting and Stopping of an Intermittent Supersonic Wind Tunnel. K. G. Winter and C. S. Brown. (*NATO AGARD 9th Wind-Tunnel & Model-Testing Panel, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 65*, Aug., 1956. 16 pp. Measurements given for the loads on a model during starting and stopping at Mach Numbers of 2.00 and 2.48. The use of a model loading coefficient in terms of tunnel stagnation pressure is proposed.

Transonic Wind Tunnel Testing Techniques. I—Historical and General Introduction. H. F. Vessey. **II—Design and Operational Problems of the Transonic Jet-Driven Wind Tunnel.** J. A. Kirk. **III—Design and Operational Problems of the Electrically-Driven Transonic Wind Tunnel.** R. Hills. **IV—Some Aspects of Transonic Tunnel Operation in Industry.** F. E. Roe. **V—The Assessment of Results Obtained in Transonic Wind Tunnels.** F. O'Hara. **VI—Summary of the Discussions.** John A. Dunsby. *RAeS J.*, Jan., 1958, pp. 1–31. 15 refs.

• **Bendix Aviation Corporation . . .** Pacific Division has opened an analog computing facility in the Systems Analysis Branch, the firm announced.

• **Consolidated Controls Corporation** has bought the Aircraft Products Division of Manning, Maxwell & Moore, Inc., and has named three new district sales managers: Robert L. Hogan, mid-continent district out of Tulsa; Lamar F. Kirby, southeast at Atlanta; and Arthur H. Barnes, Pacific coast at Los Angeles.

• **Cornell Aeronautical Laboratory, Inc.,** reports that it is developing an airborne control system for the Lacrosse missile and lightweight launching and handling equipment in order to make the system transportable by helicopter.

• **The Garrett Corporation** has announced the appointments of Jack Lewis to the newly established position of Director, Manufacturing, and Vice-President Frank Miles to head the firm's Sales Divisions.

• **General Dynamics Corporation . . .** Convair Division has announced the election of J. V. Naish as President of the division and Senior Vice-President of the firm. He succeeds retiring Gen. Joseph T. McNarney who will continue with the firm as a consultant and member of the Board of Directors. Major assembly of the Convair 880 began on April 10, the firm announced. . . . Stromberg-Carlson Division reports that plans are completed for an automation data service to supply operating tapes for numerically controlled machine tools.

• **General Electric Company's** Missile Guidance Section has opened a Western District Office at 6607 W. 80th St., Los Angeles. . . . Fred W. Newman has been named Manager, Aircraft Product Service, Instrument Department. . . . James E. Schwartz has been reassigned as Manager, Northwestern District, Aviation and Defense Industries Sales Department. James J. Bingham filled his former post as Manager, Southwestern District.

• **General Precision Equipment Corporation . . .** Kearfott Company, Inc. (western division) has announced the appointment of Leslie G. Davidson to the Sales Engineering Staff and named the Bertram D. Aaron Company, of Los Angeles, engineering sales representatives for southern California. . . . Link Aviation, Inc., Board of Directors has elected Robison Clark Controller.

• **G. M. Giannini & Co., Inc.,** has named Raymond G. Hanson, Jr., Manager—Sales Promotion and Advertising. Walter Helms has been appointed Chief Engineer, Transducer Division, Pasadena, Calif.

• **Lockheed Aircraft Corporation** has announced the appointment of M. Carl Haddon as California Division Director of Marketing. Haddon formerly was Chief Engineer of the division. . . . Georgia Division rolled out the second JetStar prototype in March and named N. A. Keller JetStar Project Engineer.

The 59K is called a "unique and radical VTOL aircraft" by Piasecki Aircraft Corporation, the firm developing it for the Army Transportation Research and Engineering Command. All major components—dual engine power plant, rotors, and controls—are said to be housed compactly in the flat, low chassis. Lift is derived from two horizontal three-bladed rotors, just 3 ft. above the ground. Piasecki reports extensive ground tests were conducted on a strain-gaged balance rig, mounted on the bed of a large trailer truck.

• **Marquardt Aircraft Company** has announced the appointments of Robert K. Wead and Paul J. Papanek as Assistant Directors, Customer Relations. . . . Don L. Walter, Vice-President—Engineering and Van Nuys Operations, has been named Chairman of the NACA subcommittee on engine performance and operation and a member of the power-plants committee. Other Marquardt engineers serving on NACA subcommittees are John A. Drake, ASTRO Director—internal flow; William G. Bennet—combustion; and R. T. Dungan—power-plant controls.

• **North American Aviation, Inc.** . . . Autonetics Division has announced the appointment of Walker M. Mahurin as Divisional Representative, Western Region Office.

• **Northrop Aircraft, Inc.,** reports that the company's President and chief executive officer, Whitley C. Collins, has been elected a member of the board of trustees of California Institute of Technology. . . . Nortronics Division has established two major operating elements—an Electronic Systems and Equipment facility at Hawthorne, Calif., and a Systems Support facility at Anaheim. Heading the first facility is Frederick Stevens, formerly Chief, Missile Guidance and Controls. Thomas H. Quayle, formerly Manager, Northrop-Anaheim, heads the Systems Support organization. Ross F. Miller has been appointed Chief Engineer, Electronic Systems and Equipment.

• **Reaction Motors, Incorporated,** reports that it is stepping up development of the rocket engine for the X-15. The firm has assigned the name Pioneer to the engine.

• **Republic Aviation Corporation** reports that eleven of its F-105's are undergoing tests at four different corners of North America.

• **Solar Aircraft Company** has licensed three divisions of Carrier Corporation to manufacture and use a number of its special Alcermet protective coatings on heating and water heating equipment, the firm announced.

• **Sperry Gyroscope Company Division of Sperry Rand Corporation** has announced formation of a new Countermeasures Division and the appointment of Norman L. Winter as Manager. Edward M. Brown has been named Treasurer of the firm.

• **Union Carbide Corporation . . .** Linde Company has announced an agreement with Detroit Steel Corporation in which Linde will build an automatic oxygen plant at Detroit's Portsmouth, Ohio, operations.

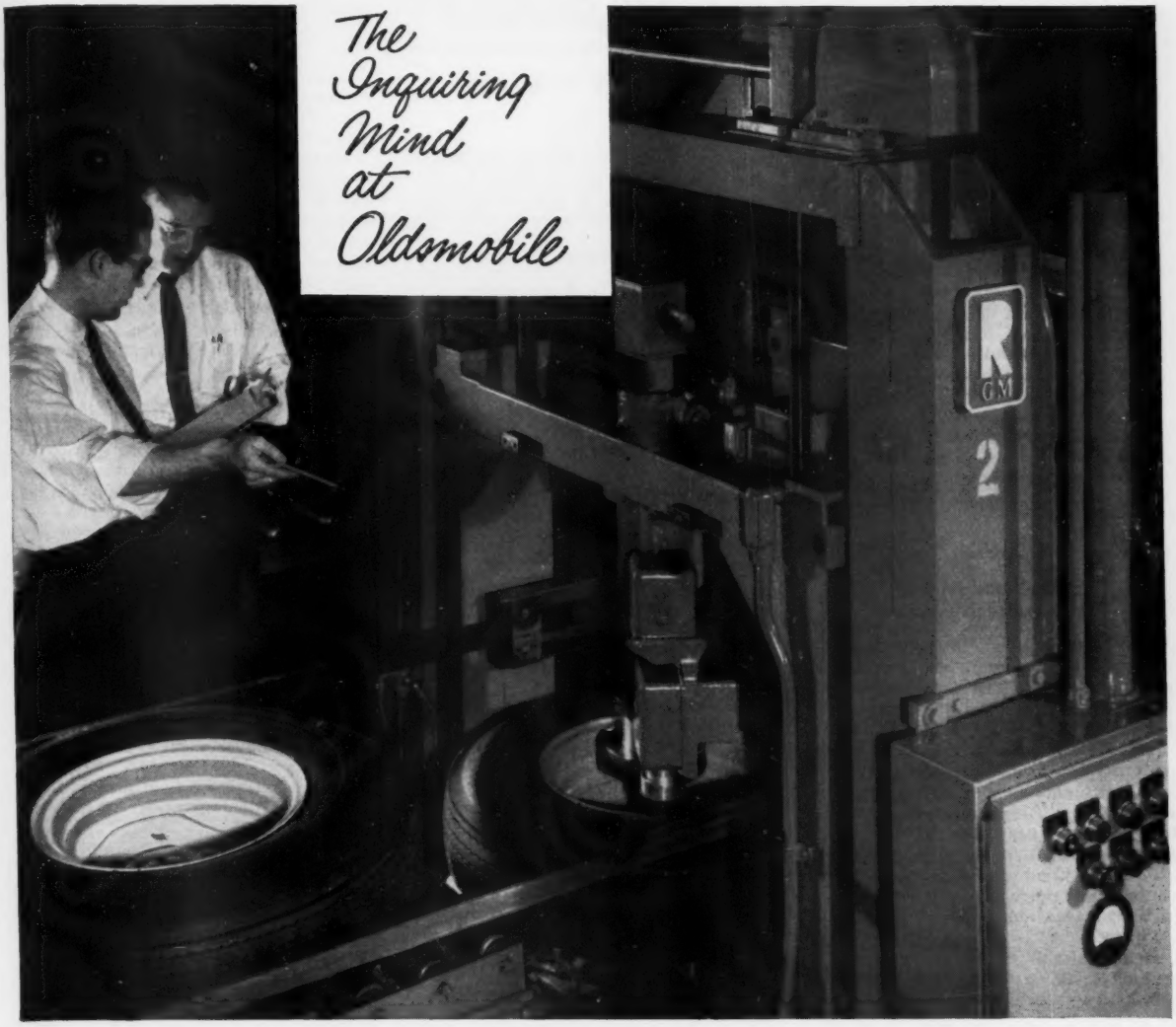
• **United Aircraft Corporation . . .** Pratt & Whitney Aircraft has announced that it will supply a jet engine for primary power for a new USAF air-to-surface missile—North American's Hound Dog.

• **United States Rubber Company . . .** Tire Division announced that it will install a 7-ton-wheel, tire-testing device that will spin at 300 m.p.h. at its Detroit tire development laboratory for testing aircraft tires. The firm also announced the formal opening of its branch at 5900 First Ave. South, Seattle, Wash.

• **Vertol Aircraft Corporation** reports that its Model 44 transport has been certificated by the CAA.

• **Westinghouse Electric Corporation** has established in Baltimore a new applied research laboratory for the development of radically new electron devices, advanced-type tubes, solid-state devices, microwave tubes, and information storage tubes. G. Ross Kilgore, formerly Director, Army Signal Corps' Electron Device Division, was named Manager of the laboratory.

XUM



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Sputnik Only a Part of IGY Program

To the scientist, the Russian and American satellites are a contribution rather than the most important part of the IGY program, according to Richard W. Porter, a Consultant to General Electric Company. Dr. Porter spoke to 400 members of the Section and the Dayton Engineers Club on January 22.

He went on to explain the purpose and specific objectives of the IGY. He also reviewed the details of world-wide participation by various nations.

JOHN S. MCCOLLOM, *Secretary*

Hampton Roads Section

Water-Based MATS and the SeaMistress

Guy Mallery, Advanced Design Department Project Engineer, The Martin Company, presented "The Case for Water-Based Air Logistics" at the February 4 meeting.

Mr. Mallery described SeaMistress aircraft around which Martin has developed a logistics concept for modern limited ground wars. The aircraft is in the Mach 0.9 speed range, has a span of 200 ft., wing area of 6,000 sq.ft., normal gross weight of 250 tons, payload of 50 tons over a 3,500 nautical mile range, capability of landing in 10-ft. waves, and is powered by eight J-75 jets.

He said that the SeaMistress uses a new type of plastic on the hull bottom which permits it to land and take off on snow or ice without damage. Ice build-up on the afterhull in cold water is no problem because jet exhaust turns water spray to steam.

Mr. Mallery said a fleet of 1,000 SeaMistresses can move three divisions, including their heaviest equipment, in about 15 days compared to 45 days by ship and 25 days for the current MATS fleet of 900 planes.

PAUL A. HUNTER, *Secretary*

Rocky Mountain Section

Cryogenics in Aeronautics

Seventy-three members and guests heard Richard Bosworth discuss the relation between aeronautics and cryogenics at the February 5 meeting. Mr. Bosworth, Manager, Beech Aircraft's Boulder Division, shared the rostrum with Dean Holben who outlined Beech's activities in cryogenics.

Later, members visited the National Bureau of Standards Boulder Laboratory inspecting cryogenics, radio propagation, and radio standards facilities.

D. A. KNOWLTON, *Secretary*

San Antonio Section

Search for Scholars

Members put to work plans for finding gifted high school students Feb. 18–20 when a special subcommittee of the Student Activities Committee surveyed preliminary activity at a local science fair.

The subcommittee evaluated some of the exhibits in an attempt to recognize young talent. Another survey was scheduled for March 14.

Colonel Leigh H. Hunt, USAF, Section Chairman, initiated the idea after discussion with other Section Chairmen at the IAS 26th Annual Meeting. The plan has been motivated by the Federal project for providing funds for 40,000 additional scholarships.

▶ Colonel Jarvis P. Jones discussed "Human Engineering" at the February 14 meeting at Lackland AFB Officers Club. He described the training of recruits and officers at Lackland using charts to show how 120,000 men are processed each year.

COL. LEIGH H. HUNT, *Chairman*

Texas Section

Air Force Flight Safety

Colonel J. C. Bailey, USAF, spoke on "Aircraft Safety" at the January 24 meeting. Colonel Bailey is Deputy Director, Flight Safety Research.

He said that the Air Force accident rate decreased steadily except when the Army flew the mails and during the World War II expansion and demobilization. Material failure, a cause of bad accidents, has increased from 28 per cent to 41 per cent since 1954. During the same period, pilot error has decreased from 57 per cent to 49 per cent, he said.

M. V. RICCIUS, *Secretary*

Tullahoma Section

Ideal Inlet Design

A. C. Frazer, Supervisor, Internal Aerodynamics, Northrop Aircraft, Inc., discussed "Supersonic Inlet Design" at the February 26 dinner meeting.

His topic covered the necessary design for matching inlet ducts to turbojet engines to achieve maximum engine thrust and minimum aircraft drag.

H. A. REICHMANN, JR., *Secretary*

Washington Section

Turbine Transports Force CAA Growth

The government's view of "Turbine Transports in Civil Operation" was given by James T. Pyle, Administrator, Civil Aeronautics Administration, at the November 12 meeting.

He reviewed problems arising from the introduction of turbine transports telling, in some cases, how they will be solved. Current Operations and Airworthiness Regulations will be amended to handle the wide speed range spread of newer aircraft, variation of power with ambient temperatures, emergency procedures for fuel dumping, and other related activities.

Mr. Pyle outlined the current CAA program which calls for $810 million expenditure on hardware, training 2,500 new personnel each year, and the tripling of ground aids to navigation at all altitudes, between 1957 and 1962.

FLOYD J. SWEET, *Secretary*

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AERODYNAMICS

Theorie schallnacher Strömungen (Theory of Transonic Flow). K. G. Guderley. Berlin, Göttingen, Heidelberg, Springer-Verlag, 1957. 376 pp., figs. DM 42.–. In German.

The present volume, which presents a connected account of the theory of transonic flow, takes into account the body of definite knowledge acquired in this area since World War II. Transonic flow, the transition from subsonic to supersonic flow, creates special difficulties from both the physical and the mathematical points of view; research in this field is accordingly characterized by an especially close interweaving of physical and mathematical thought. More space has been devoted in the book to mathematical considerations than is usual in dealing with flow problems since it is necessary, in treating of transonic flow, to rely more on fundamentals and to obtain a more refined mathematical treatment than subsonic or supersonic flows require.

The author considers that the objectives of his work will have been attained if, on the one hand, it will give the aerodynamicist an understanding of the mathematical methods and conclusions of transonic flow theory and, on the other, it will point out to the applied mathematician the mathematical problems that have been posed by the physical problem, with the result that he will be able to close up existing gaps, to simplify the progression of his thought, and to enrich the field with new methods. To keep the book from being too extensive, the author has omitted certain investigations that can be readily consulted in the literature: the discussion of the existence of a potential flow in a supersonic region enclosed by a subsonic region and the characteristic features of a lifting wing theory in the transonic region.

Contents: (1) General Fundamentals. (2) Simplification of the Differential Equations of Flow; Similarity Law for Transonic Flows. (3) Linearized Treatment of Transonic Flows. (4) Exact Solutions of the Potential Equation for Transonic Flows. (5) The Fundamentals of the Hodograph Method. (6) Discussion of Transonic Flow Fields with the Aid of the Hodograph. (7) Particular Solutions of the Tricomi Equation. (8) Flows with Mach Number Equal to Unity. (9) Flow Fields Differing Only Slightly from a Flow with Mach Number Equal to Unity. (10) Individual Investigations Utilizing the Particular Solutions of the Form (Eq. 3, Sect. 3, Chap. 7). (11) Axially Symmetric Flows. Literature Index. Subject Index.

AERONAUTICS, GENERAL

First Flights. Oliver Stewart. London, Routledge and Kegan Paul, Ltd.; New York, Pitman Publishing Corporation, 1957, 1958. 225 pp., illus., diagrs. $5.50.

Each of the flights recorded is distinguished either by its practical application of important technical innovations or by its extension of the uses of civil or military aircraft.

AIRCRAFT

Proceedings of the Florida Conference on High-Speed Aerodynamics and Structures. Held at the University of Florida, Gainesville, January 21–24, 1957. Vol. 1. (ARDC Technical Report 57-46, ASTIA No. 113,003.) Sponsored by the Air Research and Development Command, The Glenn L. Martin Company, Northrop Aircraft, Inc., and the University of Florida. Baltimore, Martin, 1957. 190 pp., illus., diagrs., tables.

Contents: The Effects of Dissociation and Ionization on Hypersonic Couette Flow, H. W. Liepmann and Z. O. Bleviss. A New Method for Providing Continuous High-Temperature Air Flow for Hypersonic Research, A. Hertzberg and R. Weatherston. Temperature Distributions in Composite Structures, J. F. Lundeberg. Design Requirements and Laboratory Simulation of the Kinetic Heating of Aircraft Structures, J. W. Taylor. The Estimation from Simple Tension Data of Creep Rupture Characteristics in the Presence of Initial Complex Stress Gradients, J. W. Freeman and H. R. Voorhees. Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals, J. V. Gluck, H. R. Voorhees, and J. W. Freeman. Materials Evaluation and Design Criteria, G. Sachs and K. N. Tong. Mechanical Property Data Requirements for New Weapons Systems, D. A. Shinn and R. F. Klinger. Thermal Property Data Requirements for New Weapons Systems, J. I. Wittebort. Factors of Safety in the Presence of Creep, N. J. Hoff. Lift and Drag Forces on Cone-Cylinder Bodies in a Rarefied Gas, S. A. Schaaf and T. Nark. Some Research on Short and Long Time Thermal Effects, G. Gerard. Determination of Inelastic Stresses at Elevated Temperatures by Strain Analysis, B. E. Gatewood. Thermal Stress Analysis by Energy Methods, L. A. Riedinger. The Creep of Structural Joints, L. Mordfin. Simplified Equations for Calculating Local and Total Heat Flux to Non-Isothermal Surfaces, E. R. G. Eckert, J. P. Hartnett, and R. Eichhorn. A Procedure for Calculating the Boundary-Layer Development in the Region of Transition from Laminar to Turbulent Flow, J. Persh. Effects of Extreme Surface Cooling on Boundary-Layer Transition, J. R. Jack, N. S. Diaconis, and R. J. Wisniewski.

CHEMISTRY

Surface Chemistry, Theory and Applications. 2nd Ed. J. J. Bikerman. New York, Academic Press, Inc., 1958. 501 pp., illus., diagrs., tables. $15.

This second edition of a book published 10 years ago as "Surface Chemistry for Industrial Research" treats surface chemistry as a part of physical chemistry and stresses its relationship to all other parts and to physics and chemistry in general. Material included in the book has been grouped under such main headings as liquid-gas, liquid-liquid, solid-gas, solid-liquid, solid-liquid-gas and solid-liquid-liquid, and electric surface phenomena. The author is with the Massachusetts Institute of Technology.

COMBUSTION

Chemistry Problems in Jet Propulsion. S. S. Penner. (International Series of Monographs on Aeronautical Sciences and Controlled Flight.) New York, Pergamon Press, 1957. 394 pp., diagrs., tables. $12.50.

Written to give research workers some understanding of principles utilized in sciences outside of their major field of specialization, this book varies in emphasis between qualitative surveys and more detailed discussions of selected topics. The work on atomic and molecular structure aims at providing a sensible appreciation of modern concepts derived from application of wave mechanics. The subject of combustion thermodynamics is treated in detail to enable students to learn to predict optimum performance of propellants in rocket engines. The last part of the book is devoted to a discussion of chemical reactions in flow systems.

The author is Professor of Jet Propulsion, Daniel and Florence Guggenheim Jet Propulsion Center, California Institute of Technology.

CONTROL SYSTEMS

Feedback Control Systems. Otto J. M. Smith. New York, McGraw-Hill Book Company, Inc., 1958. 694 pp., diagrs., tables. $13.50.

Intended for the first year of graduate study, this textbook presents a unified philosophy for the

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The latest information on this interesting metal. This up-to-date progress report explores the potential usefulness of vanadium, and provides a comprehensive treatment of its extraction, properties, and processing. If you are seeking new materials for specific applications, you will find this book a handy reference. A publication in the *Wiley Series on the Science and Technology of Materials: J. H. Hollomon, Advisory Editor.* 1958. 185 pages. $8.50

3. CENTRIFUGAL AND AXIAL FLOW PUMPS:

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By R. A. GRANGE, United States Steel Corp., F. J. SHORTSLEEVE, D. C. HILTY, W. O. BINDER, all of the Electro Metallurgical Co., G. T. MOTOCK, Olin Mathieson Chemical Corp., and C. M. OFFENHAUER, the Electro Metallurgical Co.

A concise summary of all the available data on four of the important alloying metals for iron and steel. Complete, accurate information, some of it for the first time in published form. The fourth publication in the *Alloys of Iron Research New Monograph Series: Frank T. Sisco, Director.* 1957. 533 pages. 207 illus. $14.00

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By A. G. GAYDON, Warren Research Fellow of the Royal Society

A clear, authoritative treatment of important new experimental techniques for controlling flames and for exciting flame-type spectra, developed in the last decade. Techniques cover burners for flat diffusion and flat premixed flames, flames supported by free atoms, flash photolysis, shock-tube excitation, and use of isotope tracer methods. 1957. 280 pages. Illus. $9.00

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analysis and design of feedback systems in such varied fields as economics, sociology, government, conservation, biological populations, process control, mechanics, or guidance. It is divided into four successive parts: Linear Analysis, Linear Synthesis, Steady-State Nonlinear Analysis, and Nonlinear Synthesis. The relationships are given between the open-loop transient, sinusoidal, or statistical response and the closed-loop transient, sinusoidal, and statistical responses, any one of which may be the basis for the computation of the remaining five.

The author is Professor of Electrical Engineering, University of California, Berkeley.

Basic Feedback Control System Design. C. J. Savant, Jr. New York, McGraw-Hill Book Company, Inc., 1958. 418 pp., illus., diagrs. $9.50.

This book attempts to teach the fundamentals of servodesign by means of practical examples and from the student's own point of view. The author makes several deviations from more conventional methods of presentation. One difference is in the use of the root-locus method as a basic tool for servodesign. Another is to present servotheory and practical servodesign without the requirement of an elaborate mathematical background. Problems are included at the end of each chapter.

The author is Director of Engineering, American Electronics, Inc., and Visiting Associate Professor of Electrical Engineering, University of Southern California.

FLUID DYNAMICS

Fluid-Dynamic Drag; Practical Information on Aerodynamic Drag and Hydrodynamic Resistance. Sighard F. Hoerner. The Author, 148 Busteed Drive, Midland Park, N. J., 1958. 416 pp., illus., diagrs., figs. $15.

The present volume represents a completely revised and enlarged edition of the author's *Aerodynamic Drag* which was published in 1951. In size, it has been substantially doubled, and five of the chapters are entirely new—those dealing with Wind Forces on Structures, Hydrodynamic Drag, Water-Borne Craft, Complete Aircraft, and Drag at Transonic Speeds. The title has been changed to reflect the additional material on hydrodynamics and water-borne craft. The compilation is extensive, and the available material on the subject is evaluated critically with correlation between experiment and theory. This reference work has been written with the needs of the engineer, researcher, and student in mind and should be useful not only to aeronautical engineers but also to those who must solve problems involving aerodynamic or hydrodynamic drag. The whole field of transportation is covered, and the text is supplemented by close to 2,000 bibliographical references. The page size has been enlarged to 8½ by 11 in., and some 600 illustrations are included. Dr. Hoerner is at present acting as a specialist for aerodynamics and hydrodynamics in the field of naval architecture at Gibbs & Cox, Inc.

Contents: 1, General Information (Background, Notation). 2, Skin-Friction Drag (Including Laminar Airfoils). 3, Pressure Drag (Predominantly Experimental). 4, Wind Forces on Structures (Wind Pressure). 5, Surface Irregularities (All Types of Roughness). 6, Drag of Streamline Shapes (Bodies and Foil Sections). 7, Drag Due to Lift (Primarily Induced Drag). 8, Interference Drag (Predominantly Statistical). 9, Internal-Flow Systems (Engine Cooling Scoops). 10, Hydrodynamic Drag (Including Cavitation). 11, Water-Borne Craft (Ships, Planing). 12, Land-Borne Vehicles (Automobiles and Railroad). 13, Aircraft Components (Canopies, External Stores). 14, Complete Aircraft (Performance). 15, Influence of Compressibility (Drag Divergence). 16, At Transonic Speeds (Base, Missiles). 17, At Supersonic Speeds (Foils, Hypersonic Wings). 18, Drag at High Speeds Affected by Viscosity & Rarefaction (and at Highest Speeds). Subject Index.

MATERIALS

Dislocations and Mechanical Properties of Crystals; An International Conference Held at Lake Placid, September 6–8, 1956. Edited by J. C. Fisher, W. G. Johnston, R. Thomson, and T. Vreeland, Jr. Sponsored by the Air Force Office of Scientific Research, Air Research and Development Command, and by the General Electric Research Laboratory. New York, John Wiley & Sons, Inc., 1957. 634 pp., illus., diagrs., tables. $15.

This presentation of the principal methods for observing individual dislocations is made up of contributions by 54 of the world's authorities in the field. It reviews the parts of the field which are most complicated and least understood thus helping to clarify the present state of progress in the field. The book is divided into sections containing material on direct observations of dislocations; deformation of pure single crystals; work hardening and recovery; alloy crystals, impurities, and yield point phenomena; dislocation damping and fatigue; the theory of dislocations; whiskers and thin crystals; and radiation damage.

Kaiser Aluminum Sheet and Plate Product Information. 2nd Ed. M. B. Baker and J. M. Adle, Editors. Chicago, Kaiser Aluminum &

XUM

Chemical Sales, Inc., 1958. 308 pp., illus., diagrs., tables.

Published for the use of designers, production personnel, engineers, and purchasing executives concerned with the fabrication of sheet and plate aluminum, this manual is designed to serve as a guide to the proper selection and use of aluminum sheet and plate alloys. It also outlines preliminary considerations and fundamental factors of the various methods of aluminum fabrication. Many of the major methods of manufacturing and fabrication are briefly discussed for rapid analysis. Included are brief descriptions of sheet and plate production, composition and specifications of alloys, their applications, fabrication and finishing methods, together with engineering data. The tables present listings of properties to simplify and speed reference work.

MATHEMATICS

The Taylor Series; An Introduction to the Theory of Functions of a Complex Variable. P. Dienes. 552 pp., figs. $2.75. Reprint of the 1931 edition.

A Treatise on Plane and Advanced Trigonometry. 7th Ed. E. W. Hobson. New York, Dover Publications, Inc., 1957. 383 pp., diagrs. $1.95. Reprint of the 1928 edition entitled *A Treatise on Plane Trigonometry.*

MECHANICS

Dynamic Instability; Automobiles, Aircraft, Suspension Bridges. Y. Rocard. Translated from the French by M. L. Meyer. New York, Frederick Ungar Publishing Company, 1957. 227 pp., illus., diagrs., tables. $9.50.

In this book, the theory of dynamic stability is applied to various problems of sufficient technical practicality to warrant a comparison of theoretical and practical results down to numerical detail. To this end, the phenomenon of self-excitation due to coincidence of two natural frequencies is employed as a guide to an understanding of the general nature of dynamic instability. Chapters 5, 6, and 7 are devoted to the author's results for the three great problems of the directional instability of automobiles, the instability of suspension bridges under wind pressure, and flutter in aircraft wings while Chapter 8 summarizes the known work on the longitudinal stability of aircraft, particularly as treated by von Kármán and Biot.

The author is Professor in the Faculty of Science, University of Paris, and Director of the Physical Laboratory, Ecole Normale Supérieure.

The Scientific Papers of Sir Geoffrey Ingram Taylor. Vol. 1, Mechanics of Solids. Edited by G. K. Batchelor. Cambridge, Eng., At the University Press; New York, Cambridge University Press, 1958. 593 pp., illus., diagrs., tables. $14.50.

A pioneer researcher into the mechanics of solids and fluids, G. I. Taylor has also been responsible for considerable progress in related sciences such as aeronautics and meteorology. This first volume contains all of Taylor's studies on the mechanics of solids, including papers on elasticity, plasticity, the properties of metals, and dislocation theory. A number of the papers (written for government departments or advisory committees) are here made generally available for the first time. The editor is at Trinity College, Cambridge.

NUCLEAR ENERGY

Sourcebook on Atomic Energy. 2nd Ed. Samuel Glasstone. Princeton, N.J., D. Van Nostrand Company, Inc., 1958. 641 pp., illus., diagrs., tables. $4.40.

Prepared at the request of the Atomic Energy Commission, this enlarged and revised *Sourcebook* brings together important facts about the past history, current status, and the possible future of atomic and nuclear science. The work includes material on the identification of hitherto unknown fundamental particles, the transmutation of new elements, advances in the use of isotopes, and improved experimental techniques and equipment, as well as a new chapter on nuclear reactors. The author is a Consultant to the Atomic Energy Commission.

Progress in Peaceful Uses of Atomic Energy, July-December 1957. United States Atomic Energy Commission. Washington, Superintendent of Documents, January, 1958. 463 pp., diagrs., tables. $1.25.

The period covered by this report saw rapid progress in development of nuclear reactors to produce electric power and in international cooperation. These gains, the Nation's other atomic achievements for peaceful purposes since 1954, and the Commission's contributions to those gains are described in a special section, incorporated in this report, entitled "Progress in the Peaceful Uses of Atomic Energy—A 3-Year Summary." In addition to Chapter I, which chronicles the actions and gains for 1957 and preceding years, Chapter II describes Progress with Radioisotopes; Chapter III, Progress with Power Reactors; Chapter IV, Growth of the Atomic Energy Industry; Chapter V, Progress in International Cooperation; and Chapter VI, Progress with Physical Research.

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By C. E. EASTHOPE

February 1958, 277 pp., illus., $7.80

FATIGUE IN AIRCRAFT STRUCTURES

Proceedings of the International Conference held at Columbia University, 1956

Edited by A. M. FREUDENTHAL

1956, 456 pp., illus., $12.00

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Edited by L. MARTON

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POWER PLANTS

1957 Aircraft Spark Plug and Ignition Conference Report, Toledo, Ohio, September 24-26. Sponsored by Champion Spark Plug Company. Toledo, Ohio, Champion Spark Plug Company, 1957. 112 pp., illus., charts.

Contents: Spark Plug Service Experience. Spark Plug Fouling. Effects of Fuel & Lubricants on Spark Plugs. Recondition, Test & Inspection of Spark Plugs. Research and Development. Ignition Analyzers. Magnetos—Harness—Leads. Jet Ignition. Review of Champion Aircraft Spark Plug Manufacturing Improvements. Research and Development Expansion Program. Résumé of Research and Development Activities. Index.

PRODUCTION

Ceramic Fabrication Processes. Edited by W. D. Kingery. Published Jointly by The Technology Press of Massachusetts Institute of Technology, and John Wiley & Sons, Inc., New York, 1958. 235 pp., illus., diagrs. $9.50.

The outgrowth of the 1956 Special Summer Program in Ceramics at M.I.T., this book contains contributions by 22 scientists and engineers concerned with particular phases of ceramic processing. The contributors evaluate the significance of current developments and indicate probable directions of future progress. Thus the volume provides both the technical basis and present practice of ceramic fabrication and shows the relationship between principles and the art. Offering a comprehensive treatment of both traditional and novel ceramic methods, it covers such fabrication steps as forming, firing, and resultant properties as affected by fabrication. Consequently, a basis is provided for both selecting and using fabrication methods for problems arising in traditional and new ceramic materials.

The editor is Associate Professor of Ceramics, M.I.T.

Proceedings of the EIA Symposium on Numerical Control Systems for Machine Tools, Los Angeles, September 17-18, 1957. Sponsored by the Engineering Department of the Electronic Industries Association; With Participation by Aircraft Industries Association, National Machine Tool Builder Association, National Electrical Manufacturers Association, and Office Equipment Manufacturers Institute. New York, Engineering Publishers, 1957. 106 pp., illus., diagrs.

Contents: Opening Remarks, C. B. Thornton. Keynote Address, C. S. Irvine. Control System Definition, Oliver A. Foss. The Numericord System, Henry Ankeny. Digimatic Control System—Technical Description, Jack Rosenberg. Standardization in Numerical Control Systems, Joseph Harrington, Jr. The Bendix Tape Control System, Murray Kanes. General Electric Numerical Contouring Control, G. R. Peterson. The Cincinnati Numerical Control System, J. M. Morgan. The Giddings & Lewis Numericord, D. H. Bingham. Programming the "D" on the Digimatic System, Jack Rosenberg, M. R. Rosenfield, and Jerry Ostland. Bendix Tape Preparation System, E. C. Johnson. Terminology of Tape Preparation for Tape-Controlled Machine Tools and Computer Programming, O. Dale Smith. Programming for the Cincinnati Numerical Control System, Richard C. Messinger. Univac and Tape Preparation, D. A. Fauble. A Machine Tool Builder Looks at Numerical Control, Ralph E. Cross. Summary of AIA Activities in Numerical Control, George E. Kinney. Developments in Electronic Control of Machine Tools, Edward E. Kirkham.

Plastic Sheet Forming. Robert L. Butzko. New York, Reinhold Publishing Corporation, 1958. 181 pp., illus., diagrs. $4.50.

Written to introduce the engineer and designer to the field of plastic sheet forming, this guide also provides an explanation of the various techniques of forming for the manufacturing technician. Instead of trying to provide technical answers to all the problems confronting the sheet forming industry, it attempts to bring together all the scattered information in the field and present it in a useful form. Applications and other pertinent information related to plastic sheet forming are surveyed, and sheet forming use in over 14 different kinds of products is explained. Also included are material selection, equipment, molds, sheet decoration, and costs.

The author is a partner in the Auto-Vac Company, an equipment producer for the plastic sheet forming industry.

SPACE TRAVEL

The Space Encyclopaedia; A Guide to Astronomy and Space Research. Edited by M. T. Bizony and R. Griffin. New York, E. P. Dutton & Co., Inc., 1957. 292 pp., illus., diagrs., tables. $6.95.

The subjects treated in this encyclopedia range from guided missiles and various aspects of upper atmosphere research to the composition and structure of the remotest galaxies, but the emphasis, from an astronomical viewpoint, has been placed on the solar system. The articles on Astronomy, Cosmology and Radio Astronomy, and those on Guided Missiles and Rocketry are recommended as general introductions to their respective subjects.

UPPER ATMOSPHERE

The Threshold of Space; The Proceedings of the Conference on Chemical Aeronomy. Edited by M. Zelikoff. Sponsored by Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, Cambridge, Mass., June 25-28, 1956. Coordinated by Wentworth Institute. New York, Pergamon Press, 1957. 342 pp., illus., diagrs., tables. $15.

Contents: I, *Atmospheric Photochemistry—Earth and Venus.* Chemistry of an Oxygen-Nitrogen Atmosphere, C. A. Barth and J. Kaplan. Theory of the Night Airglow, D. R. Bates. Solar and Terrestrial Phenomena Resulting from Photoelectric Effect of Solar X-Rays, L. Vegard. A Discussion of the Reactions of Nitrogen and Nitrogen Oxides in the Upper Atmosphere, P. Harteck. Nitrogen Oxides and the Airglow, M. Nicolet. A Study of the Airglow Emissions at 5577, 5890 and 6300 Å with a Photometer of High Spectral Purity, E. R. Manring and H. B. Pettit. Speculations on the Atomic Hydrogen and the Thermal Economy of the Upper Ionosphere, S. Chapman. The Formation of Ozone by Electrical Discharges in the Atmosphere: Experimental Results and the General Aspects, A. T. Vassy. The Atmosphere and the Cloud Layer of Venus, G. P. Kuiper. II, *Spectroscopy and Photochemistry.* Vacuum Ultraviolet Spectra of the Afterglows of Pure N_2 and a Mixture of N_2 and O_2, Y. Tanaka, A. Jursa, and F. LeBlanc. Metastable States in Photochemistry, G. Porter. Photochemistry of Nitrous Oxide in the Far Ultra-Violet, M. Zelikoff and L. M. Aschenbrand. Photodetachment of Atmospheric Negative Ions, L. M. Branscomb. The Photolysis of Water Vapor, H. A. Taylor and M. C. Chen. Radiation Chemistry of the Nitrogen-Oxygen System at Low Pressures, S. Dondes. Mass-Spectroscopic Determination of Photoionization Products, R. F. K. Herzog and F. F. Marmo. Recent Data on the 'Vacuum Sliding Spark' Spectrum and its Use for Absorption Spectrophotometry in the Far Ultra-Violet, N. Astoin, J. Romand, and B. Vodar. Some Data on the Absorption Spectra of Gaseous N_2O, NO, and H_2O in the Extreme Ultra-Violet, N. Astoin, A. Johannin-Gilles, J. Granier-Mayence, and J. Romand. Vacuum Ultra-Violet Spectra and Molecular Ionization Resolution, K. Watanabe and J. R. Mottl. Autoionization Considered in Relation to Excitation and Electron-Capture Processes, W. R. S. Garton. Termolecular Reactions and Chemiluminescence, A. D. Walsh. The Energy Levels of the Nitrogen Molecule, R. S. Mulliken. The $^5\Sigma$ Level of the Nitrogen Molecule, O. Oldenberg. Charge Transfer and the Mobilities of Positive and Negative Ions in Their Parent Gases, A. Dalgarno. Rotational Transition of Hydrogen Molecules by Collision, K. Takayanagi. Spectroscopic Studies of Solids Condensed at 4.2°K from Electric Discharge Through Nitrogen, Oxygen, Hydrogen, Water, and Ammonia, H. P. Broida. Abstract: Mass Spectrometric Study of the Kinetics of Nitrogen Afterglow, G. B. Kistiakowsky and J. Berkowitz. III, *Rocket Probing of Upper Atmosphere.* Far Ultraviolet Radiation in the Night Sky, E. T. Byram, T. A. Chubb, H. Friedman, and J. Kupperian. The Dissociation of Oxygen at High Altitudes, E. T. Byram, T. A. Chubb, and H. Friedman. Direct Measurements of the Night Airglow, M. J. Koomen, R. Scolnik, and R. Tousey. Emission from Sodium Ejected from Rockets, J. F. Bedinger, S. N. Ghosh, and E. R. Manring. The Formation of an Artificial Ion Cloud: Photoionization of NO by Solar Lyman Alpha at 95 Km, F. F. Marmo, J. Pressman, L. M. Aschenbrand, A. S. Jursa, and M. Zelikoff. A Synthetic Atmospheric Chemiluminescence Caused by the Release of NO at 106 Km, J. Pressman, L. M. Aschenbrand, F. F. Marmo, A. S. Jursa, and M. Zelikoff. IV, *Phenomena Produced by Supersonic Flight.* Some Problems in the AeroThermodynamics of Hypersonic Flight, W. H. Dorrance. Electric Potential in an Argon Shock Front, J. W. Bond, Jr. Absorption Coefficient of Air from 2000°K to 18,000°K, R. E. Meyerott. Approach to Equilibrium Ionization Behind Strong Shock Waves in Argon, H. E. Petschek and S. Byron. Abstract: Vibrational Relaxation in Oxygen and Nitrogen, W. Bleakney. The Application of the Shock Tube to the Study of the Aerothermal Problems of High-Speed Flight, A. Hertzberg and J. G. Logan, Jr. Experimental Techniques for the Study of High-Speed Flight, Y. A. Yoler. Applications of High Explosives in the Production of Extreme Velocities and Pressures, F. J. Willig. The Scientific Value of Shaped-Charge Particles in Upper Atmosphere Research, G. C. Throner and D. E. Shonerd. Molecular Beam and Glow Flow Visualization Studies, S. A. Schaaf, F. C. Hurlbut, and W. B. Kunkel. Dissociation of Air Behind Strong Shock Waves, E. L. Resler, Jr., and B. B. Cary. Closing Remarks: M. Greenberg. List of Participants.

VIBRATION

Vibration Control. John N. Macduff and John R. Curreri. New York, McGraw-Hill Book Company, Inc., 1958. 465 pp., diagrs., tables. $9.00.

Written primarily for mechanical engineering students at the senior or first-year graduate level, this book discusses and indicates the practical as

(Continued on page 161)

Personnel Opportunities

This section is for the use of individual members of the Institute seeking new connections and eligible organizations offering employment to specialists in the aero/space industry. Any member or eligible organization may have requirements listed without charge by writing to the Secretary of the Institute.

Wanted

Aeronautical Engineering—Faculty position available in Department of Aeronautical Engineering. Applicant should have advanced degree and some teaching experience. Should be able to teach aerodynamics, stability and control, and aircraft design at graduate level. Academic rank and salary (GS-11 to GS-13) will be dependent upon qualifications of applicant. Address replies to: Dean G. R. Graetzer, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Engineers (Aeronautical, Electrical, Electronic, Industrial, General, Mechanical, and Power-Plant), **Electronic Scientists, Metallurgists, Physicists, Technologists**—Vacancies exist for professional personnel in the above positions. Starting salaries range from $4,480 per annum to $8,645 per annum. The Naval Air Material Center is currently engaged in an extensive program of aeronautical research, development, experimentation, and test operations for the advancement of Naval aviation. Personnel are needed for work on projects involving modification, overhauling, and testing of aeronautical equipment, materials, accessories, power plants, launching and arresting devices, and for modification and structural testing of aircraft. They are also needed for work involving the basic design of catapults, launchers, arresting gear and their component parts; test and development work at shore stations and on board U. S. Navy ships, evaluation of new equipment and establishment of performance parameters, and applied research on the many problems relevant to this field. Interested persons should file an Application for Federal Employment, Standard Form 57, with the Industrial Relations Department, Naval Air Material Center, Naval Base, Philadelphia 12, Pa. Applications may be obtained from the above address or information as to where they are available may be obtained from any first or second class post office.

Assistant Project Weights Engineer—To handle preliminary design weight estimating, develop methods for estimating, and assist in controlling weight on aircraft designs. Prefer graduate engineer or major in engineering subjects with 3 or 4 years' applicable experience. **Aircraft Loads Project Lead Engineer**—To supervise the calculation of structural static and dynamic loads, determine structural design criteria, and develop methods for load analysis on manned aircraft designs. Bachelor of Science Degree in Aeronautical Engineering required, Master's Degree preferred, 5 to 7 years' related experience in aircraft loads work. Apply to: Supervisor, Aircraft Engineering Personnel, Bell Aircraft Corporation, Post Office Box One, Buffalo 5, N.Y.

Aerodynamics Research Engineer—To fill position in engineering department of leader in air handling industry. M.S. in mechanical or aeronautical engineering, five years' experience in stress analysis and design of turbomachinery, and three years' experience in internal aerodynamics of turbomachinery required. Applicant should have desire to fit into a small research group doing long-range development on centrifugal and mixed-flow compressors for commercial and industrial application. Salary open. Liberal benefits program. Contact: Westinghouse Electric Corporation, Sturtevant Division, Damon Street, Hyde Park, Mass. Telephone: Hyde Park 3-3700, Ext. 341.

Professor, Aeronautical Engineering—Development of graduate program with possible headship of Department. Industrial salary scale, consulting opportunity. Ph.D. required. Address: Dean, School of Engineering, University of Wichita, Wichita 14, Kan.

Assistant Professor and Instructor in Aeronautical Engineering—Positions are open for teaching and research in several subjects. An advanced degree is required for the rank of Assistant Professor. Send résumé of education, experience, and field of interest to Chairman, Aeronautical Engineering Department, University of Kansas, Lawrence, Kan.

Engineers—Needed for expanding program of helicopter development. Airframe and controls designers, helicopter experience desirable; mechanical designers, helicopter transmission or engine transmission experience desirable; instrumentation and electronics engineers, particularly with experience in automatic stabilization and control of droned aircraft. Also test pilots with helicopter test experience. Write to: Personnel Director, Gyrodyne Company of America, Inc., St. James, Long Island, N.Y.

Engineers—Fairchild Engine Division of the Fairchild Engine and Airplane Corporation, Deer Park, Long Island, N.Y. Diversified engineering positions are available involving engine research, design, design and performance analysis, test engineering, compressor and turbine design, controls systems, and other engineering operations associated with the general field of design and development of gas turbine power plants. These opportunities result from expanded programs in a new plant and gas turbine laboratory. Send résumé to: Felix Gardner, Fairchild Engine Division, Deer Park, Long Island, N.Y.

859. Head of Mechanical Engineering Department—Developing department in industrial city; new curriculum and laboratories being designed. Industrial salaries matched, opportunity for consulting, Ph.D. or D.Sc. required.

Available

862. Publications Supervisor—B.S. and M.S.; 7 years' experience in most phases of publication work. Has been employed by airframe, engine, and research organizations. Supervised, as well as written, edited, and produced government specification handbooks, brochures, reports, displays, etc. Record of quality work produced on schedule. Desires permanent position.

861. Aerodynamicist—With extensive research and development experience would like spare-time assignments involving editing technical or popular scientific papers or translating French or German technical papers.

860. Senior Thermodynamics Engineer—Age 32. B.S.M.E. (Aero.), 1949. Eight years' experience in analysis and design of anti-icing and related systems. Systems include thermal anti-icing, thermal de-icing, and pneumatic boot installations with application to airfoils, wind shields, and air intakes. Heavy experience in the design of icing test models and conduction of tests in the prominent icing research tunnels. Also design and test experience with air conditioning equipment, ejectors, air intakes, heat transfer and aerothermodynamic studies. Desires interesting and challenging work in a responsible position with a growing company.

858. Assistant Professor—Teaching experience of both undergraduate and graduate courses in aeronautical engineering department. Has engaged in extensive theoretical work. Desires more challenging position in teaching.

857. Aeronautical Engineer—M.Ae.E. Age 37; ex-chief engineer of leading Latin American airline, broad technical and administrative experience. Also teaching experience at university level. Languages: English, Spanish, French. Desires field service, technical representation of company affording future and opportunity, or chair at university. Desired location: South America.

The number preceding the notice represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.

856. Research and Development Engineer—B.S., M.S. in E.E., Ph.D. candidate. Seven years' experience in automatic flight controls and dynamical analysis for aircraft and missiles. Extensive experience in ballistic missile area including re-entry dynamics. Licensed pilot. Desires challenging position and increased responsibility in area of advanced flight vehicles and weapons systems.

855. Engineer—B.S. in Ae.E. and M.E. One year experience as analytical engineer in performance analysis of jet engines and gas turbines and 1 year experience in mechanical design of machines. Résumé furnished on request.

854. Engineer-Executive—Age 40, B.S.M.E., Purdue and Stanford Universities. Twelve years' experience in aeronautical research, development, and test; 6 years' experience in engineering sales and general industrial engineering; licensed. Four years' foreign work, Europe and Latin America, as engineer in Diplomatic Service; speaks French, Spanish, Italian. Relatively recently with research and engineering, Office of Secretary of Defense, Pentagon. Last position Assistant to Vice-President, Foreign Operations, top engineering-construction organization. Former officer Marine Corps Aviation; licensed pilot. Top level contact work past 10 years. Available for foreign or domestic assignment any location and any amount of travel; married, no children. Interested particularly in engineering sales and/or management in position paying upwards of $18,000. Will send complete résumé on request.

853. Aeronautical Engineer—Age 33; 16 years' aviation experience. B.S. Aero. Presently production engineer on gas turbine aircraft engines. Desires shift to missile propulsion, static or flight testing. Résumé on request.

852. Aerodynamics Engineer—Aircraft, missile, and propulsion fields. Available for part-time consulting in New York area. Twelve years' experience in subsonic and supersonic aircraft design, ram-jet and turbo-jet performance and research. Interested in active engineering, technical editing or technical adviser in research and/or development investment for domestic and European companies, in the areas outlined above. Résumé of educational, industrial, and research experience and accomplishments available on request.

851. Engineer—B.S. in M.E. Eleven years' experience as stress, design, and project engineer on rotary wing aircraft; 12 years' experience as stress and test engineer on fixed-wing aircraft. Desires position on East Coast where experience would be useful on varied assignments in aircraft or missile field with greater responsibility. Résumé furnished on request.

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Books (Continued from page 158)

well as the theoretical aspects of vibration control. It attempts to provide the student with basic theory and application in this area essential to an engineering understanding and comprehension of the fundamentals of the subject and to prepare the student for future study and development by pointing out limitations of the elementary theory and indicating problems and methods for advanced study and application. The material presented has been selected so as to have as broad a coverage of the field as possible, ranging from elementary vibration theory through such specific studies as rotor balancing, vibration isolation, steady-state and transient response, and sound-control problems. In order to prepare the student for future development, the authors list the assumptions made in idealizing actual systems for purposes of analysis and indicate the effect these assumptions will have upon the practical results of their analysis.

Mr. Macduff is Professor of Mechanical Engineering, College of Engineering, Duke University, while Mr. Curreri is Professor of Mechanical Engineering, Polytechnic Institute of Brooklyn.

Index to Advertisers

Academic Press, Inc. 157
Advance Gear & Machine Corp. 24
Aeronautical Engineering Catalog 154
AiResearch Mfg. Divs., The Garrett Corp. 117
R. C. Allen Business Machines, Inc. 116
American Brake Shoe Co. ..... Back Cover
★American Steel & Wire, A Div. of U. S. Steel Corp. 7
★Amphenol Electronics Corp. 118

Bell Aircraft Corp. 93, 148
Bendix Aviation Corp. 4
Borg-Warner Corp., Pesco Products Div. 19
Burroughs Corp. ..... Inside Back Cover

★Chain Belt Co., Shafer Bearing Div. 5
Chance Vought Aircraft, Inc. 94, 95
★Chandler-Evans 153
Christie Electric Corp. 124
Clover Industries, Inc. 145
Cornell Aeronautical Laboratory, Inc. 160

★Delavan Mfg. Co. 128
Douglas Aircraft Co., Inc. 120, 121
Dow Chemical Co., The 89

Eagle Pencil Co. 134, 135
★Eastern Industries, Inc. ..... Inside Front Cover
Eitel-McCullough, Inc. 12

★Flexonics Corp. 8

Garrett Corp., The, AiResearch Mfg. Divs. 117
General Electric Co., Light Military Electronic Equipment Dept. 22
General Mills, Inc., Mechanical Div. 127
General Motors Corp.
Harrison Radiator Div. 115
New Departure Div. 141
Oldsmobile Div. 151
G. M. Giannini & Co. 148
B. F. Goodrich Co., The 86
Goodyear Aircraft Corp., Aviation Products Div. 1
Greenleaf Mfg. Co. 125

Harrison Radiator Div., General Motors Corp. 115
Holley Carburetor Co. 9
Hughes Aircraft Co. 160

Janitrol Aircraft Div., Surface Combustion Corp. 137
Johns Hopkins University, The, Applied Physics Laboratory 138

★Johns-Manville 20
Johnson Reprint Corp. 155

Kato Engineering Co. 132
★Kearfott Co., Inc. 119
Koppers Co., Inc.
Sound Control Dept. 143
Piston Ring & Seal Dept. 10, 11

Lamb Electric Co., The 96
Librascope, Inc. 16
Lockheed Aircraft Corp., Missile Systems Div. 129
Lord Mfg. Co. 14

Martin Co., The 90, 91, 158
Menasco Mfg. Co. 139
Methode Mfg. Corp. 145

National Advisory Committee for Aeronautics 92
New Departure Div., General Motors Corp. 141

Oldsmobile Div., General Motors Corp. 151

Pesco Products Div., Borg-Warner Corp. 19

Radio Corp. of America, Defense Electronic Products 133
Ramo-Wooldridge Corp., The 123
Republic Aviation Corp. 159
Resistoflex Corp. 15
★Rohr Aircraft Corp. 6, 97
Ryan Aeronautical Co., Electronics Div. 13

Sandia Corp. 158
Sargent Engineering Corp. 26
★Shafer Bearing Div., Chain Belt Co. 5
★Simmonds Aerocessories, Inc. 146
Society for Experimental Stress Analysis 124
Southern California Cooperative Wind Tunnel 144
Surface Combustion Corp., Janitrol Aircraft Div. 137
System Development Corp. 140

★U. S. Steel Corp., American Steel & Wire Div., Columbia-Geneva Steel Div., Tennessee Coal & Iron Div., U. S. Steel Export Co. 7

Westinghouse Electric Corp., Air Arm Div. 130, 131
John Wiley & Sons, Inc. 156

★ *Specifications and further information on the missile, rocket, and aircraft products of these companies will be found in the*

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Published Annually by

INSTITUTE OF THE AERONAUTICAL SCIENCES

2 East 64th Street New York 21, N.Y.